HOW TELEGRAPHS AND TELEPHONES WORK

EXPLAINED IN NON-TECHNICAL LANGUAGE

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HOW TELEGRAPHS AND TELEPHONES WORK

EXPLAINED IN
NON-TECHNICAL LANGUAGE

BY

CHARLES R. GIBSON

AUTHOR OF
"THE ROMANCE OF MODERN ELECTRICITY," "ELECTRICITY OF TO-DAY,"
"SCIENTIFIC IDEAS OF TO-DAY," &c. &c.

WITH FIVE ILLUSTRATIONS AND TEN DIAGRAMS

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PREFACE

THE author has received from time to time letters from readers of his *Romance of Modern Electricity* and *Electricity of To-day*, who have found those books of service to them as teachers, suggesting additions to them to cover other details of interest to those who occupy themselves seriously with the subject.

He has not hitherto seen his way to comply with these very courteous suggestions, his desire being to keep those books easily within the grasp of the general reader. But a request has recently reached him for a small book in simple non-technical language dealing with telegraphs and telephones, such as would be useful to those who are specially interested in those instruments. In the present volume the author has endeavoured to comply with this suggestion, and at the same time to give to the general reader a short and vivid account of those modern marvels. He has amplified in several directions what has already appeared in those parts of the earlier volumes which relate to telegraphs and telephones, and has added a chapter on wireless telephony and a short discussion of the electron theory. He has included, by request, a chapter entitled "Concerning Lightning."

Preface

The author is again indebted to Professor Magnus Maclean, D.SC., M.I.C.E., M.I.E.E., for very kindly reading the proof-sheets. Also to William Allan, A.M.I.E.E. (Chief Electrician to the National Telephone Company at Glasgow), for reading the chapters dealing with telephony; and to J. Erskine-Murray, D.SC., F.R.S.E., M.I.E.E. (Consulting Electrician), for reading those parts dealing with wireless telegraphy and telephony.

February, 1909.

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THERE is no subject connected with the material world which appears to us more mysterious than *electricity*. As a matter of fact *gravitation* is just as mysterious, but we have grown up with the phenomena of gravitation constantly in evidence around us, so that there is no apparent mystery until we seek to inquire into the nature of this force by which one lump of matter attracts another.

Then, again, we feel as if there was not the same mystery about the phenomena of light, but this is only because we have, in the eye, a sense-organ which is directly affected by *light waves*, whereas we have no sense-organ to respond directly to *electric waves*. Nevertheless, we shall see later that these two kinds of *waves*, or disturbances in the all-pervading ether of space, are in reality of exactly the same nature.

How Telegraphs and Telephones Work

In order to try and dispel, as far as it is possible, the mystery surrounding our subject it will be well to consider how we came to know anything about electricity. Without entering into much detail, it will be sufficient to note that at some far distant date, long before the dawn of the Christian era, some person observed the very simple fact that when a piece of amber was rubbed it would attract little pieces of straw or other light objects towards it. The ancient philosophers solved the problem in a very simple manner by declaring that friction gave the amber heat and life. Their idea was, evidently, that when they imparted life to the amber by rubbing it, it was able to draw any light object towards itself. The strange thing is that one generation after another were content either to ignore the existence of the phenomenon or to accept the foregoing picturesque solution of the problem. Century after century went past, and amber still got the credit for being different from other forms of matter in being able to attract other bodies towards it. Had people taken the trouble to rub any piece of ordinary glass, sulphur, or resin, they would have discovered that this phenomenon was quite a common property of matter. No one seems to have made such inquiries until the beginning of the seventeenth century, when one of Queen Elizabeth's physicians, Dr. William Gilbert, made a series of most valuable experiments. He discovered that any substance when rubbed would exhibit this attractive property in some measure. He could offer no suggestion as to what took place within the substance, but he very wisely coined a name by which we should distinguish this mysterious agent. Although Gilbert had proved that the phenomenon was common to all substances, he called it after amber, as that was the one substance with which this attractive property had been associated

for so many centuries. The Greek word for amber being *elektron*, Gilbert christened the subtle agent with the name of *electricity*, and when a body was *excited*, or rubbed, and exhibited this attractive property, it was said to be *electrified*.

At first it was thought that the metals could not be electrified, as all attempts to excite them by rubbing produced no signs of attraction. It seems to have occurred to some one that possibly the rubbing did produce electricity and that it escaped by the experimenter's hand to the earth as quickly as it was produced. We find that the early experimenters affixed glass handles to metal rods, and by means of these they were able to show that metals could be electrified just as other substances were. As long as the experimenter did not touch the metal, but held it by the glass handle, the electricity could not escape. Here was direct evidence that electricity could travel through some substances, while its way of escape seemed to be cut off completely by other substances. And so we speak to-day of conductors and non-conductors, or *insulators* of electricity.

The terms *conductor* and *non-conductor* are merely relative. We might say that all bodies will conduct electricity, provided the current has sufficient pressure to overcome the resistance offered to its passage, but a very bad conductor might be damaged or destroyed by a high-pressure current. The difference between the conducting properties of some materials is as great as is a drop of water to a mighty ocean; or perhaps a better analogy would be to say that while a pipe or tube will conduct water, a solid log of wood will also do so, but in a very different degree. The metals are very good conductors of electricity, silver and copper being the best; and being very nearly equally good, copper is, of course,

preferred for economy, and it is this property of copp which has so increased the demand for the metal durii the last half-century. Glass, porcelain, slate, marbl india-rubber, cotton, and silk, are all such poor condu tors that they have been termed non-conductors insulators. Between the metals and these come son materials which are neither good conductors nor goo insulators; and it must be borne in mind that the terms are merely comparative, for a substance migl be a conductor for one purpose and an insulator fo another.

It was an easy matter to discover by experiment wh substances, when rubbed together, produced the be results, but to be constantly rubbing pieces of glass wit silk cloth, or pieces of sulphur or resin with woollen clotl meant the expenditure of a good deal of personal energ In order to electrify bodies more easily men made simp machines, in which a glass cylinder or plate was revolve by a handle and caused to rub against leather cushion Most of us have at least a nodding acquaintance wit such electrical machines. In the modern type of thes there is no real friction, but two glass or vulcanite plate each carrying a series of small slips of thin metal foil upo them, are made to revolve close to each other in opposit directions, so that an electric charge is *induced* on th plates and suitably collected by neighbouring pieces metal which are insulated. Within recent years som electrical machines have been made in which plai vulcanite plates, without any metal foil, have been usec When these are driven at a high speed, by means of a moto they give very good results. Our present interest in thes early electrical machines lies in the fact that they led u to later discoveries which have brought electricity int our every-day life.

It was when experimenting with one of these machines, about the close of the eighteenth century, that Professor Galvani, of Bologna, observed that the legs of a freshly killed frog were convulsed by an electric discharge. It seems to have occurred to Galvani to try if a lightning discharge would have the same result, and he was about to suspend the frog's legs by a copper skewer to the iron railing on the balcony of his house, when he observed the twitching to take place as soon as he placed the copper skewer in contact with the iron railing. Galvani jumped to the conclusion that the animal tissue contained electricity, that the brain secreted it, and that it was communicated to the body by the nerves, while the muscles acted as reservoirs.

Another Italian professor, Alessandro Volta, of Pavia, repeated Galvani's experiments; but he declared that the electricity did not reside in the animal tissue, but was produced by the contact of the two pieces of dissimilar metals—the copper skewer and the iron railing. A very profitable discussion took place between these two celebrated philosophers, but Volta was soon able to prove his contention to be correct. He made up a pile of discs of copper and zinc, placing between each pair a piece of cloth moistened with acidulated water (a few drops of sulphuric acid in water). After building up a pile with a number of pairs or couples arranged as described, Volta connected a wire to the zinc disc at the top of the pile, and another wire to the copper disc at the bottom; and when he brought the free ends of the two wires together, he was able to show an electric spark on again separating the wires. This amply proved Volta's point that the electricity was not in the frog's tissue. (See Fig. 1.)

The pieces of moistened cloth in Volta's pile soon

dried up, thus interfering with its action, and this led Volta to immerse each pair of copper and zinc pieces in a separate vessel filled with acidulated water. This new arrangement greatly enhanced the effect. A number of such chemical cells connected together was called a battery, signifying a battery of cells, but nowadays one often hears a single cell erroneously called a battery. Our present batteries are all merely modifications of Volta's early chemical cell. (See Fig. 2.)

There was such a marked difference in the behaviour of the electricity produced by these voltaic cells and that obtained from the frictional machines, that their identity was doubted for more than a generation, so that the one was designated "frictional" and the other "voltaic" electricity.

When a body was electrified by one of these frictional machines, the charge dissipated with lightning suddenness the instant a way of escape to earth was provided. On the other hand, the electrical effect produced by the chemical battery was so very different, continuing to flow quietly along a connecting wire, that it was picturesquely named "the electric current," which term has become a household word with us.

Turning for a moment to consider how magnetism became known, we find it a long look back in the world's history to the discovery of a peculiar stone, or iron ore, which it was observed would attract small pieces of iron to it, and would pass on its attractive power to pieces of iron without any appreciable loss to itself. It was further observed that when an oblong piece of this stone was freely suspended, it would always come to rest in a definite position, one end pointing in the direction of the north pole of the earth, and the other, of course, pointing southward. The utility of this directive property

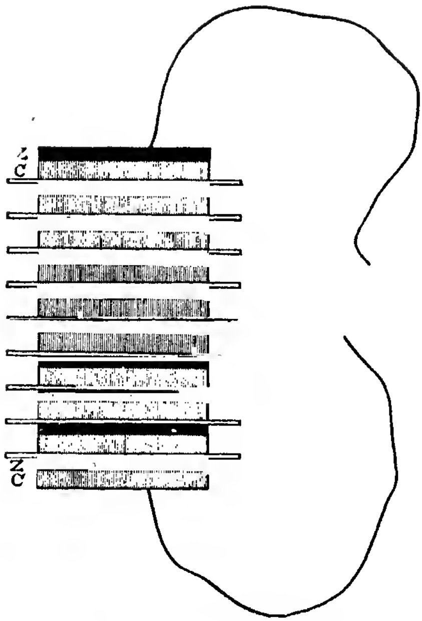


FIG. 1.—THE EARLIEST ELECTRIC BATTERY

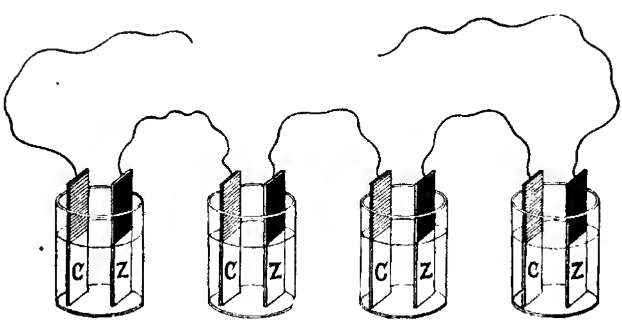


FIG. 2.—VOLTA'S BATTERY OF CELLS

was very early recognised, and made use of by travellers when crossing the deserts, the stone receiving the name of leading-stone or lodestone.

Steel magnets were well known at the time of Volta's discovery of the electric current, but years elapsed before it was observed that an intimate connection existed between magnetism and electricity. This discovery has been of immense value to us, for when a Danish professor, early in the nineteenth century, observed that a small magnet or compass needle was affected by an electric current passing in a neighbouring wire, he discovered the fundamental principle upon which nearly all modern applications of electricity have been built up. What Oersted, the Danish philosopher, did find was simply that, if a wire was stretched over or under a magnetic needle, the magnet would turn round and take up a position at right angles to the wire. The effect was enhanced if, instead of using a single wire, a long wire was coiled up, so that the current would pass round and round in the neighbourhood of the magnet. The movement of the magnet produced in this way has given us telegraphs, electric bells, etc., and it is this very turning power which drives our electric railway trains and tramway cars. (See illustration on p. 65.)

About a dozen years later it was discovered by our illustrious Faraday, while experimenting in the Royal Institution (London), that the converse of this action between an electric current and a magnet was also true, for he found that if a coil of wire was quickly moved in the neighbourhood of a magnet, an electric current was generated in the moving coil. Here indeed was a crowning discovery, for it gave us the principle of the dynamo, the advent of which has made it possible to produce electric currents on a large scale at a small cost.

The Starting Point

We have now seen the very simple experiment with rubbed amber lead up to the construction of "frictional machines." Then it was observed that these machines produced a certain twitching effect in a frog's legs, and that the same movement resulted if they were touched by two pieces of dissimilar metals in contact with each other. From this simple discovery the "battery" was evolved. Then, commencing with the lodestone or natural magnet, found in many parts of the earth, we find the intimate connection between electricity and magnetism experimentally discovered, and we are now in a position to follow the great modern development of these simple but all-important discoveries in the telegraphs and the telephones of the present day.

Before turning our attention to these it will be well to make one or two properties of magnetism and electricity quite clear.

If we take a straight bar of steel which has been magnetised, we find one of its ends or "poles" marked with the letter N, signifying that the magnet would turn this end towards the north pole of the earth, when freely suspended or supported so that it could revolve upon its centre. Seeing that one end invariably turns northwards and the other southwards, it is only logical to suppose that there must be some difference between the two ends. We find by simple experiment that each end attracts iron equally well, so that there is no difference in their attractive powers, but if we take two straight bar magnets we find a very interesting phenomenon. Each has one end marked N, signifying the north-seeking pole, but more shortly called the north pole of the magnet, the other end being called the south pole. On bringing the north pole of the one magnet

towards the south pole of the other, we find a powerful attraction, but if we bring one north pole towards the other north pole, we find no attraction whatever, and on trying the two south poles together, we find they also will have nothing to do with each other. We shall see this better still if, for one of the magnets, we use a large compass needle delicately balanced on a pivot at its centre. We now bring the north pole of a bar magnet near the north pole of the compass needle, and we find not only no attraction but a very decided repulsion, for the latter turns away its north pole, and if we follow up its retreat with the bar magnet, the compass needle will always keep at a respectful distance. The moment we turn the south pole of the bar magnet towards it, it is forcibly attracted. In this simple way we can demonstrate the very important fact that, while either pole of a magnet is equally attractive to iron or steel, the two magnets behave very differently towards one another. A north pole and a south pole will always attract each other, but the north poles repel one another, as also do the south poles.

We have already seen that when an electric current passes along a wire there is an effect produced quite outside of the wire, for a magnet placed in its neighbourhood will turn round at right angles to the wire. Has the electric current, then, some magnetic force? Certainly it has, and we can very easily demonstrate this by a simple experiment. In order to get as big an effect as possible, we shall coil the wire up into a small circle or rectangle, and as we wish the current to go round the whole length of the coil, we must take a wire with some insulating covering, to prevent the current taking a short cut across from the leading-in to the leading-out end of the coil, without troubling to pass

through the length of the wire. We make the coil as light as possible, by using a very fine copper wire covered with silk yarn wound round and round the wire. We then suspend the coil, so that it may be freely moved to and fro, and having connected the ends of the coil to a battery, we send an electric current through the coil. We then bring the north pole of a bar magnet near the face of the coil, and we find that the coil is attracted, just as though it were a steel magnet. We then present the same pole of the magnet to the other face, or back of the coil, and we find it is repelled, so that there is not the slightest doubt that this coil of copper wire, with an electric current, is like a magnet, having one face a north pole, and the other a south pole. This is of immense practical value to us, for here we have a magnet completely under our control. The moment we send a current through the coil it becomes a magnet, but immediately we stop the current, the magnetism disappears. We further find that we can make the poles change places at will, for if we send the current in at one end of the coil, the north pole appears at the front face of the coil, but if we reverse our connections to the battery, and send the current through in the opposite direction, we find the south pole at the front face and the north now at the back. We have therefore a magnet which we can make powerful or weak according to the amount of current we send through the coil, and we can also change the position of its two poles at will.

If we place a rod of soft iron in the coil, so that it forms a core to the surrounding coil, which does not necessarily touch it, we find that we have a much more powerful attraction, as though the iron had concentrated all the attractive power which surrounds the wire. The iron will now lift a considerable weight, but the

moment the current ceases in the surrounding coil, the iron lets go its burden. A coil of wire with a soft iron core is called an electro-magnet, and is under complete control. If we wind a length of insulated wire around a kitchen poker and attach the ends of the wire to a battery, the poker will immediately become a magnet. If we use a bar of hard steel in place of iron, we shall find it more difficult to magnetise, but when once magnetised it will remain so, after the controlling current has been withdrawn. While artificial magnets were originally made by stroking the metal with a piece of lodestone, they are now manufactured just in the way we magnetised the poker, and if made of steel so that they retain the magnetism, they are called permanent magnets, in contradistinction to the electro-magnets which are temporary.

The meaning of an electric circuit is to many persons a mystery, and even to connect up a bell, battery, and push seems to be, to some people, a difficult operation. There is no reason why this should be so, for all we have to do is to provide a path for the current through each piece of apparatus. I remember that as a boy I formed the habit of always picturing electricity as a very "fly" customer, for it would keep its eyes open for every short cut, and it would never go a roundabout way, unless it was left no option in the matter. To take the case of a bell, battery, and push. Suppose the battery to consist of a cylinder of carbon and a rod of zinc, and we connect these two *elements* by a wire. When the carbon and zinc elements are immersed in a jar containing a solution of sal-ammoniac, a current of electricity will flow along the wire from the carbon to the zinc, and on reaching the zinc, we may imagine it passing through the liquid to the carbon, and again along the connecting

wire, and so on; the battery being somewhat analogous to a pump. We cut the wire and connect the two ends to the bell terminals, so that the current must now pass round an electro-magnet in the bell. The bell would now ring, and continue ringing as long as it is thus connected, but if we cut the connecting wire at any place, the bell immediately stops ringing, as the current has no path left. We now connect the broken ends to the "push," which, in its normal position, still gives the current no path, but which, when pressed, makes a metallic contact between the ends of the wires, picturesquely acting just as a drawbridge. As long as the circuit is kept closed by pressing the push, the current gets through to the bell, but as soon as the push is released the circuit is again broken. It is therefore clear that we always require a complete circuit for a current of electricity. Perhaps the clearest view is got by picturing the current trying to get across from the top of the carbon to the top of the zinc in the cell, and in allowing it to do so we may provide quite a long path, forcing it to pass through our apparatus on its way.

The important points which we must particularly bear in mind, are those relating to the intimate connection between electricity and magnetism, for in the following chapters we shall see that telegraphs and telephones are dependent entirely upon this relationship.

CHAPTER II

REMARKS CONCERNING THE ELECTRIC CURRENT

Methods of preventing the escape of the current—The electric pressure of the current—A simple analogy—How we increase the electric pressure—Whence we get electrical energy—Dry cells—Accumulators—Can we store electricity? The origin of the Leyden jar—Electric pressure of an accumulator—Producing electric currents by mechanical motion—Michael Faraday's historic discovery—The dynamo.

FOR the present we shall not trouble about the nature of the electric current; we shall consider it merely as a convenient term for describing something which apparently travels along the wires connected to a battery or dynamo.

From what we have seen in the preceding chapter it is obvious that we must always insulate the conducting wires if we wish to prevent the electric current escaping to earth. There are two ways of doing this. We may suspend the wire in the air, by means of poles carrying pieces of porcelain, to which the wires are fastened. As porcelain is a non-conductor the electric current cannot escape. The second method is to cover the whole wire with some insulating material. In this case the insulating cover is somewhat analogous to the metal of a waterpipe. If we are conducting water at a very low pressure, a pipe of thin material is sufficient, but if the water is at a great pressure we require to add very considerably to the strength of the pipe. In similar

manner we find that a simple covering of cotton or silk thread gives sufficient insulation for an electric current of very low pressure, such as is obtained from a common chemical battery. But when we come to use currents at high electric pressure we have to provide a much more substantial insulation, in which india-rubber usually plays an important part. If a wire is sufficiently insulated it may be laid upon the earth, or buried beneath the ground.

Consider the term *electric pressure,* and the meaning of the word *volt.* If we have water flowing through a pipe we may measure the pressure exerted by the water, and this we state as being so many pounds to the square inch. When we have electricity flowing along a wire we may measure the electrical pressure, but we cannot state this in any ordinary measures, and so we coin a word to represent a unit of electric pressure. The British Association, who arranged this unit for us, named it after the illustrious Italian, Professor Volta, who discovered the means of producing electricity by chemical process. The volt is a definite multiple of the absolute unit of pressure, which was scientifically determined, but the reader may form an idea of its value from the fact that the electric pressure at which any primary cell delivers its current is always between one and one and a half volts. The layman cannot hope to form any very definite conception of the values of electrical units if he never has occasion to use them. He would have no very definite idea of the value of a pound weight or a yard length unless he had some practice in the use of these.

The electrician does not often use the term electric pressure; he prefers to speak of it as electromotive force, and to save time writes it down E.M.F. He

says that this electromotive force is due to a difference of electric condition or "potential" between the ends of the conductor in which the current is flowing, just as one might say that the pressure of water in a river is due to the difference of level of the two ends of the river. We therefore say that there is a certain difference of potential between the terminals of a battery or a dynamo. As to the nature of this difference of potential we have no idea. In the case of a river perhaps we are prone to imagine that we understand more than we really do We certainly know that the pressure is due to the difference of level and we say that the water falls by gravity, but we have no idea as to the nature of this force. By experiment we find that the potential or pressure of the current from a single chemical cell or "battery" is never more than from one to two volts. It varies according to the materials used in the construction of the cell. We may make the cell as large as we like, and therefore obtain a greater current, but we can never increase its pressure or electromotive force. A barrel of water twenty feet above sea-level is at the same pressure as a lake at the same level. While we cannot increase the electric pressure by enlarging the cell, we may add the pressure of a number of cells together by connecting the carbon of one cell to the zinc of the next cell and so on. In this way we may form a battery of any desired voltage by increasing the number of cells. If, instead of connecting the cells in "series" as described, we were to connect all the carbons of the cells together and all the zincs together, that is to say, carbon to carbon and zinc to zinc, we should not have increased the pressure, for the result would be just the same as though we had made one large cell. If we had a number of barrels of water and we placed them all at the same

level, say two feet above the ground, we should find on connecting them together by pipes that the pressure remained the same as we might get from one single barrel, but if we placed each barrel two feet above its neighbour, then we should increase the pressure in proportion to the number of barrels connected together. This somewhat crude analogy may serve to clear up a point which I have found to be a stumbling-block to many.

For almost all practical purposes we connect the cells "in series" to get the increased pressure required to overcome the resistance offered by the apparatus through which we wish to send the current.

We cannot create energy; there is a definite amount of energy in the world just as truly as there is a definite amount of matter. We can only transform energy from one form to another.

It is apparent that in the battery it is chemical energy which is transformed into electrical energy; and if we continue this process until the chemical action ceases, the transformation will also stop, so that it is necessary in time to add new exciting chemicals.

These batteries of cells are called primary batteries, as also are the "dry cells," which are now so much in demand. The principle of these dry cells is just the same as in the simple cell already described, but the liquid is replaced by a moist paste for convenience of handling.

This seems a convenient opportunity of mentioning "secondary" batteries, more commonly called storage batteries or accumulators. A secondary cell may consist of two leaden plates perforated with holes which are filled in with red lead and immersed in dilute sulphuric acid. There is no chemical action between these two similar plates, so that we cannot call forth any electrical energy

as we do from a primary cell. If, however, a current of electricity from another source is passed through this secondary cell, the chemical condition of the plates is found to be entirely changed, and strange to say the change in each plate has been different. At the one plate peroxide of lead is formed, while at the other spongy lead is observed. It almost seems like a fairy tale to learn that when these two plates are now connected to each other by a wire the electricity appears to return from one plate to the other in the opposite direction to which it was passed through the cell, producing a steady electric current in the wire circuit. On further consideration it may seem less wonderful than the simple primary cell before described, for we have in this secondary cell merely made, as it were, an artificial primary cell.

In charging the secondary cell or accumulator, we have transformed electrical energy into chemical energy, which latter is really what we have stored, and which, as soon as the plates are connected by a wire, is again transformed into electrical energy. This can hardly be called storing electricity. As soon as the plates have worked back to their normal condition they become inert, but they may be recharged and so on.

I think a good analogy may be found in the simple principle of the "old grandfather's clock." When the clock is standing with its weights at the bottom and showing no signs of energy, it is analogous to the secondary cell uncharged. The weights are then raised against the pull of gravity, and some physical energy is expended by the person thus winding up the clock. In the other picture this is equivalent to the charging of the cell, the electrical source disturbing the chemical conditions of the plates. Further, the clock weights, when released, in

falling back to zero drive the clockwork, but as soon as they reach the bottom no energy is available ; analogous to this is the joining of the plates by a wire through which a current of electricity flows until the plates have reached their normal condition, when no further available energy remains to be transformed. As already remarked, it is chemical energy that is stored in these accumulators, so that we can only speak of storing electricity indirectly.

Can electricity be stored? This question naturally arose in the minds of even the earliest experimenters. These men were getting certain effects from their " rubbing " machines, and it was reasonable to suppose that if they could only store up a quantity of electricity they would get a greater effect. It had been discovered that glass offered a very great resistance to the passage of electricity, so it was suggested to try and charge some water in a glass jar, and thus prevent the accumulated electricity from escaping. Several experimenters appear to have been at work in this direction at the one time, and in the University of Leyden (Netherlands), while this experiment was being carried out, quite an alarming incident occurred. The water having been charged, the person holding the glass jar very naturally took hold of the metal which had been conveying the charge to the water, in order to disconnect it from the machine, but whenever he touched this he received a severe shock through the arms and breast. In this way it was discovered that if a conductor is charged inside a glass vessel, and having another conductor outside, as soon as the conductors are connected together there is a sudden discharge of the accumulated electric strain. In the original experiment the water formed the inside conductor, while the experimenter holding the jar was the outside conductor, but " Leyden jars " were constructed, using a tin-

foil coating both on the inside and the outside of the glass, carrying the foils about half-way up the jar. A metal connection on an upright rod is placed inside, and it is then convenient to discharge the jar by a pair of discharging tongs, touching the outside tinfoil with one prong and bringing the other near to the metal upright, when a vivid spark is seen at this point. One may consider the charged Leyden jar as having been a means of causing a strain in the ether, which, when released, suddenly springs back to normal.

In speaking of the secondary battery or accumulator, we have not considered the electric pressure obtainable. It is the same humble story of two volts per cell, and an increased pressure is obtained, just as in the case of the primary battery, by connecting the plates of different electrical conditions together. These secondary batteries are not only of great use as reservoirs, but they give a uniformly steady current, whereas the current obtainable from a primary battery diminishes rapidly, owing to hydrogen gas collecting on the carbon plates and interfering with the passage of the current. Primary batteries are all right for electric bells, telephones, etc., where there is not a continuous call upon their energy, but the accumulator is necessary where a constant current is desired.

Although telegraphs and telephones depend upon chemical batteries for their electric current, it will be well to notice, at this point, the method of obtaining electric currents from mechanical motion. We shall find this of use in connection with the A B C dial form of telegraph instrument, also in connection with the ringing-up apparatus in telephones, and again in connection with the generating of electric currents for large installations of wireless telegraph instruments.

Until the year 1831 we knew no other practical means

of generating an electric current than by chemical batteries. It is true that Professor Seebeck, of Germany, had discovered before this date that an electric current could be generated by heating the junction of two dissimilar metals; but this *thermo-electric* method was only of scientific interest as far as the production of electric currents was concerned. I am considering an electric current as distinct from an electric charge such as produced by the early *frictional* or *statical* machines.

The mechanical method of producing electric currents was arrived at in the following way: Our great British scientist, the late Michael Faraday, found that if a loop of wire were moved up and down between the poles of a magnet there was a current of electricity set up in the wire. Faraday pictured a magnetic field between the poles of the magnet, and his imagination filled this space with "lines of force," and he said it was when the coil or loop of wire passed through these imaginary lines that a current was originated. It was quite evident that it was only as long as he kept the coil moving up and down in the magnetic field that the current was present in the wire.

The next step was to mount a coil of wire on a spindle and revolve it in the space between the poles of a magnet, and, as was anticipated, the effect was greatly enhanced, because the coil could be made to pass through the imaginary lines of force much oftener. The little magneto-electric machines sometimes used for medical purposes, but perhaps oftener for amusement by dealing out electric shocks, are simply arrangements by which, when one turns a handle on the outside of the box, a coil is made to spin round in the neighbourhood of a magnet.

It then occurred to people to make such machines on a

very much larger scale, and to use steam-engines to drive the coils round at a great speed. Such contrivances were called dynamo-electric machines, which name we have discarded, merely using the word "dynamo" (Gr. *dynamis*, force).

In the small experimental machines at first constructed ordinary steel magnets were used, but in order to get a stronger magnetic field these were soon replaced by electro-magnets. A dynamo now consists of a coil or coils of wire mounted on a shaft or spindle, this part being called the armature, and driven round at a high speed between the poles of an electro-magnet.

Suitable means have been devised for conducting the electric current out from the revolving coil to the line wire. It may be led out either as a *direct* or *continuous* current, flowing steadily in one direction just as all battery currents flow, or it may be led out as an *alternating* current in which we picture the current surging rapidly to and fro, first in one direction and then in the other; a sort of vibratory current. We need not trouble with further details of dynamos for our present purpose.

CHAPTER III

HOW TELEGRAPHY CAME ABOUT

An early attempt at telegraphy—An ingenious surgeon—Other historical attempts—The discovered relationship of electricity to magnetism brings a practical telegraph—The needle telegraph—The telegraphic alphabet—The railway block system—The A B C dial telegraph.

VERY early in the world's history man found it necessary to be able to signal to a distance, and so he adopted the method of lighting beacon fires upon the hill-tops, and these primitive signals could be passed on from one point to another.

One of the earliest attempts at electric telegraphy was made about the middle of the eighteenth century. One would not expect to find any attempt at telegraphy in the days when man's only knowledge of electricity was its wild and sudden discharge from an electrical machine, and yet there exist on record several very interesting attempts in those days prior to Volta's taming of electricity into a peacefully tractable current, as we have it from batteries.

It is evident that some attempts to transmit intelligence by electricity were made as far back as the middle of the sixteenth century, although the records of these are somewhat vague, and appear to have been carried out by some monks in a German monastery.

In the *Scots Magazine* of February 1st, 1753, there appeared a letter describing a practical electric telegraph worked by a primitive electrical machine. The letter was

merely signed "C. M.," and was written from Renfrew, a small town on the River Clyde, a few miles below Glasgow.

The one property of electricity with which this ingenious writer would be most familiar was doubtless the attraction between an electrified body and any light object placed near it, and so it occurred to him that if he could charge a long connecting-wire between two places, then the distant end would attract a small piece of paper placed close to it. Having determined that this could be done, he set up twenty-six separate wires, connecting his dwelling to a distant cottage in the village. The wires were supported on insulators at short distances apart, being fixed at each of the two distant ends in a bar of solid glass, leaving about six inches of wire extending beyond the glass fixture. These six-inch ends were stiffened, so that if depressed they would spring back to their horizontal position. These free ends were then placed immediately above the glass cylinder of an electrical machine, so that while the machine was "excited" by rotating it, any of these twenty-six ends could be pressed down to touch the cylinder, and thus the whole length of this particular wire would receive a charge of electricity.

At a point close to where each wire entered the solid glass fixture the inventor suspended a short piece of wire with a metal ball at its extremity, there being, therefore, twenty-six separate balls. Immediately under each ball he placed a small piece of paper bearing one letter of the alphabet upon it. This arrangement was, of course, carried out at both ends of the line wire. To signal the letter A the operator, having set the electrical machine in motion, would take a piece of solid glass in his hand, and, depressing the end of the first wire till it touched

the cylinder, he would charge the whole of that wire so that the suspended metal ball at each end would attract its particular paper marked A. The person at the receiving end would take note of A, while the operator would see by the attraction of A at his own end that the wire had been sufficiently charged. In the same way all the twenty-six letters of the alphabet could be signalled in any desired order, thus enabling intelligible messages to be sent. The inventor says that the letters "were contrived to fall back into their proper places," so he may possibly have had a small glass division for each letter to rise and fall within.

The inventor also suggested, among other arrangements, that each of the little metal balls might by attraction be made to strike against a little gong, there being twenty-six gongs of different sounds, and the person using the apparatus would, as the inventor said, "soon understand the language of the bells." In this suggestion we have the first idea of a "sounder" telegraph, and it is by sound signals that most telegraph messages are now received.

The great difficulty in working any such apparatus as that just described would be to prevent the high tension charge from making a dash to earth through every possible means of escape, and in this connection it will be of interest to note a few sentences from the inventor's letter. He writes: "Some may perhaps think that although the electric fire has not been observed to diminish sensibly in its progress through any length of wire that has been tried hitherto; yet, as that has never exceeded thirty or forty yards, it may be readily supposed that in a far greater length it would be remarkably diminished, and probably would be drained off in a few miles by the surrounding air. To prevent this objection,

and save further argument, lay over the wires from one end to the other with a thin coating of jeweller's cement. This may be done for a trifle additional expense, and as it is an electric *per se*, will effectually secure any part of the fire from mixing with the atmosphere." Here we have, at this early date, the idea of an insulated wire as used for almost all electrical purposes at the present time.

It is interesting to note that the mental picture which this ingenious man formed of electricity was that of a "fire," which thought was very natural owing to the appearance of a spark at any point where the electricity suddenly escaped from one body to another.

The late Sir David Brewster made particular search to discover the history of this anonymous letter writer "C. M.," and his efforts met with a certain amount of success. He first of all found out that a very clever man had lived in Paisley in 1791; that he came from Renfrew, which is only a few miles distant; and that it was reported of this genius that he "could light a house with coal reek (smoke), and make lightning speak and write." At a later date Sir David Brewster found that this man's name was Charles Morrison, who was a native of Greenock, but practised for some time as a surgeon in Renfrew, and ultimately became connected with the tobacco trade in Glasgow. Morrison was counted a wizard, and his neighbours believed him to be in concert with the devil, because of the apparently supernatural power he had of sending messages to a distant cottage. He ultimately went out to Virginia, U.S., where he died.

Another early form of telegraph suggested was, that the sender and the receiver should each have a good clock, with the letters of the alphabet painted round the dial, and the two clocks keeping accurate time, the "second" hands would point to the same letter on each

dial at the same moment. By a connecting wire between the distant places a Leyden jar was made to spark at the moment the hand was opposite the letter that the sender wished to telegraph, the receiver also noting the letter indicated on his clock at the moment when the spark occurred. The first idea of this inventor had been the very primitive method of striking, with some object in his hand, upon the bottom of a copper stew pan at the moment his clock was at the desired letter, but it is evident that this method of using sound could not have been extended to any great distance. His subsequent system of using the charged Leyden jar only required one wire, but the difficulty of keeping the charge to the wire would necessarily worry the inventor if he tried it over a distance.

A very similar and better-known invention was Ronald's Electric Telegraph, in which the dials of the clocks moved round, bringing the letters of the alphabet painted upon them into view successively through an aperture in a covering case. When the desired letter appeared in the slot a signal was sent by discharging a wire at the end of which a pair of electrified pith balls, suspended by two threads, repelled each other until the discharge took place, whereupon they immediately came together by gravity. By this primitive method the words of the message were slowly built up.

After Volta's introduction of batteries the idea of electric telegraphy became more practicable. While these two last-mentioned experiments were carried out with only one connecting wire, yet it was a long time before inventors could dismiss from their minds the idea that a reliable telegraph would require a great number of connecting wires. Even one of the greatest French scientists, Ampère, suggested an instrument which re-

quired as many as thirty connecting wires, and under the end of each there was to be placed a small magnetic needle.

A few years later a German professor proposed putting the thirty little magnets inside as many coils instead of merely under the single wires; by this means the effect of the current on the magnet was greater. An instrument of this kind was exhibited at the Royal Institution of London in 1830, in which telegraph twenty-six wires, coils, and magnets were used. It was several years before any one suggested that one wire with a single coil and magnet would serve the purposes of signalling.

When one sees a magnet turning first to one side and then to the other, according to the direction in which an electric current is sent through a coil, it is a very natural step from that to the first practical electric telegraph instrument. It is apparent that if one person had the coil and magnet in his house and another had the battery at his home, while the wires still connected the battery to the coil the second person could cause the magnet beside the first to move to one side or the other at will, and by an agreed code intelligible signals could be transmitted.

The needle telegraph is just this coil and magnet and nothing more, except that it is put into a more convenient form. The magnet is fixed to a spindle passed through its centre, and is then mounted in a vertical position at the back of an upright board; the coil is then placed around it, leaving the needle free to fall to right and left. Then, so that the movements of the needle may be readily seen, an indicator or dummy needle is fixed on the other end of the spindle, which comes through to the front of the board. This indicator or needle moves, of course, along with the magnet at the back, and so the signals are

clearly read. An arrangement for reversing the current at will, in order to move the needle to one side or the other, is added, and this may be operated by moving a handle from left to right, or by depressing one or other of two small levers or "keys."

It might be a matter of agreement to signal one movement of the needle for A, two for B, and so on; but the operator would very soon weary of this plan if he had many letters far on in the alphabet to count out. Imagine our written language being constructed thus: **I** for A,

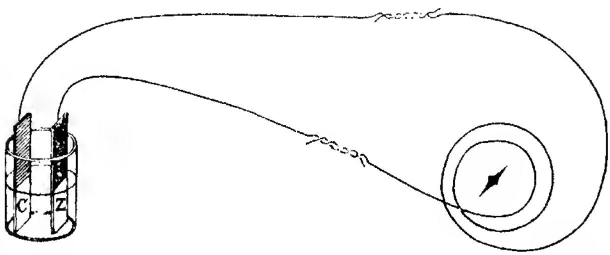


FIG. 3. SHOWING A CELL CONNECTED TO A TELEGRAPH INSTRUMENT

I I for B, **I I I** for C, and so on. It is much more convenient to let two strokes leaning against each other with a third stroke crossing them stand for **A**, three strokes placed thus for **N**, thus for **Z**; and so in telegraphy it is agreed that if the needle is moved once to the left and then once to the right (**\/**) this will signify A. It is quite remarkable that in order to construct the whole twenty-six letters of the alphabet by combinations of these two movements we never require to move the needle more than four times for any letter. It evidently did not occur to the experimenters at the outset that this could be done, as they made the early instruments with five

needles in order to get a greater variety of signal, their idea being to make the needles point out the letters on a dial.

SIGNALS FOR NEEDLE TELEGRAPH

WRITTEN THUS \

WRITTEN THUS /

A	\/	J	\///	S	\\\
B	/\\\	K	/\/	T	/
C	/\/\	L	\/\\	U	\\/
D	/\\	M	//	V	\\\/
E	\	N	/\	W	\//
F	\\/\	O	///	X	/\\/
G	//\	P	\//\	Y	/\//
H	\\\\	Q	//\/	Z	//\\
I	\\	R	\/\		

Fig. 4

Referring to the accompanying alphabet, it will be seen that the letters most often in use get the advantage of the simplest signals. Once to the left stands for E; once to the right for T; and so on. It is usual to print the left-hand strokes shorter than the right-hand ones, as shown; but this is merely for convenience of space.

Our own alphabet is of very simple construction; give a boy four straight strips of cardboard, each representing a stroke, and he can with these construct more than half the alphabet, while a few semi-circular pieces added will enable him to complete the whole twenty-six letters.

While Cooke and Wheatstone were the first (1837) to set up a needle telegraph in this country, we cannot claim the invention for them, as Professor Ampère, of Paris, had suggested fifteen years earlier that a magnet and coil placed at any distant point of a circuit would serve for the transmission of signals; and other experimenters in Germany had actually carried this out with success.

The needle instrument still holds an important position

in railway signalling; it was in that department it first gained a business footing. A special needle-telegraph instrument is also used in railway signal cabins for working the "block system." In this instrument it is arranged that the needle when deflected to the left or right remains in that position till released by the distant sending key. The needle can therefore take up three different positions, its upright or normal position, slanting to the left, and to the right. Three messages are permanently printed on the dial of the instrument, arranged so that when the needle is upright it is pointing to the words "Line blocked," to the left "Train on line," and to the right "Line clear."

The block system is very simple. Imagine a block or section of the railway track with a signal cabin at each end. These we shall call No. 1 and No. 2 cabins. When No. 1 desires to send on a train he asks No. 2 by means of another telegraph instrument if he may do so. If the way is clear, No. 2 will set the block instruments to "Line clear," and at the same time he will lower his outdoor signals. The block instruments in his own and No. 1 cabin work in sympathy with each other. As soon as No. 1 allows the train to enter the section he moves the block instrument to "Train on line," and this signal remains permanent on both instruments till No. 2 has allowed the train to pass out of the section, when he moves the indicator to "Line blocked," and at the same time sets his outdoor semaphore to "Danger." The advantage of the block system is that the information given by the one signalman to the other remains visible on the block instruments until such information has been acted upon. It relieves the signalman of the necessity of remembering the last information sent by his neighbour, but it does not relieve him of all responsible action. If the block instrument is pointing to "Train on

line," he is not prevented from sending on another train in error, but he has no excuse for such negligence.

While the needle telegraph has become practically obsolete as far as ordinary telegraphy is concerned, we shall see in the succeeding chapter that in a more sensitive form it has made ocean telegraphy a practical success. In this achievement it has scored over the Morse instrument, described in the next chapter.

In addition to these outstanding telegraph instruments there were many others invented. We see one old-fashioned friend still surviving in some rural districts in the form of the A B C dial telegraph. In this instrument an indicator is moved round a circular dial in clock fashion, and is made to point at any desired letter of the alphabet, which is printed around the dial. There is no battery required for these telegraph instruments, as each is equipped with a small dynamo or magneto-electric machine. The operator depresses, on the sending dial, the key which is opposite the letter he desires to signal. He keeps turning the handle of his dynamo until the pointer on his dial reaches this particular letter. At this point the current is cut off by the depressed key, even although he continues to drive the generator. Each complete revolution of the dynamo handle causes four distinct electric impulses to pass out along the wire, and each impulse arriving at the distant station moves the indicator of the receiving instrument one step forward. As the indicator can be moved only in one direction it is a long journey from B to A, so that messages can be spelt out only very slowly. Many instruments of this type have been invented, and these would, no doubt, have been in very wide use to-day for private lines had the telephone not provided a much quicker and more convenient means of communication.

CHAPTER IV

MORE ABOUT TELEGRAPHS

A great American invention—The origin of the Morse telegraph—How the Morse sounder works—The Morse alphabet—The Morse-inker—How a great speed is attained with Morse-inkers—An ingenious high-speed instrument—A writing telegraph—Sending several messages at the same time on one line—An ingenious multiplex system—How long distances are overcome—Handling press messages—How telegraphs are worked with a single wire—Type-printing telegraphs.

ONE might think that nothing could be simpler than the single-needle telegraph described in the preceding chapter, and yet there is a simpler method.

While Cooke and Wheatstone were busy with their pioneer work in connection with the needle telegraph, Samuel B. Morse, an art professor in New York, was experimenting with a totally different kind of telegraph. While on a voyage from Europe to America, Morse had been shown an electro-magnet by a fellow passenger. Morse quickly saw in this a simple method of sending signals to a distance by means of electricity. It was obvious that the electro-magnet might be at any desired distance from the battery as long as there were connecting wires to form a path for the electric current. It was some years before Morse was able to equip a practical telegraph line.

In the Morse system the sending operator requires only a battery and any simple means of opening and closing

the path of the current. At the receiving end is an electro-magnet, which when energised by an electric current passing through its wire, will attract the iron end of a little lever towards it. The opposite end of the lever may be made to strike a gong, or more usually merely to come against a stop, so that a clicking noise is produced each time the electro-magnet attracts the lever. This electro-magnet will therefore make a click if an electric current is sent along a wire from a battery at the distant sending station, and as there will be no attraction except when the current is passing, the lever will be pulled away from the magnet by a spring as soon as the current ceases. It is arranged that when the lever strikes the upper stop it makes a different sound from the one produced when it falls back upon the lower stop. The sounds may be described as click and clack. The sending operator can therefore, by closing and opening the battery circuit, cause the distant apparatus to make as many click-clacks as desired, and these may follow each other rapidly, or they may have a longer space of time between each. For instance, if the sending lever or battery key, which in principle is the same as an ordinary bell-push, be depressed rapidly three times in succession, three short click-clacks will be heard at the receiving end. It has been previously arranged that three sharp click-clacks will represent the letter S. One short click-clack stands for E, and one click-clack, with a longer pause between the click and the clack, for T. In this way signals have been made up for each of the twenty-six letters of the alphabet, and with these two simple signals, a short click-clack and a long click-clack, it is never necessary to use more than four of these click-clacks for any one letter. There can only be two letters, of course, having one click-clack, and the benefit is given

to the two letters which are used most frequently; E being signalled by a short click-clack, and T by a long click-clack, as already stated. Then there can only be four letters made up of two click-clacks each, and these are a short and a long click-clack for A, a long and a short for N, two short ones for I, and two long ones for M. Eight other letters are made up of three click-clacks each, arranged in different orders, while the remaining twelve letters each require four. (See Fig. 5.)

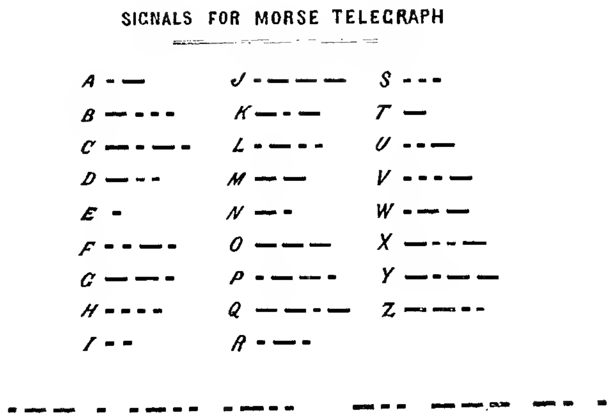


FIG. 5

These signals are the same as those at page 42; a short stroke corresponding with a left-hand movement, and a long stroke with a right-hand one.

The Morse telegraph apparatus is nothing more than the simple electro-magnet and lever, as just described. When one hands in a message in London for delivery in Edinburgh, the sending operator in London merely closes and opens his battery circuit according to the code already

described, and at the Scottish capital the receiving operator listens to the click-clacks, spelling out each letter and noting down the message thus signalled. That is to say, the person desiring to send intelligence to a distant friend writes down his message in ordinary writing, hands it in at the nearest telegraph office, where the operator's brain transforms the message into telegraphic signals, known as the Morse code. An electric current under the control of this operator then causes a distant electro-magnet to move a lever, producing a series of click-clacks, which the receiving operator translates into ordinary alphabetical letters, and again constructs the words of the message, which is written out once more in ordinary writing and delivered to the addressee. It is very probable that ere long this transformation to and translation from the Morse code will be entirely dispensed with for ordinary messages, and that the sending operator will directly control a distant type-writing telegraph instrument. The message, printed in letter form by this receiving apparatus, will be taken off the machine and delivered to the addressee just as it is received. In some measure this has long been the practice on the Continent, but the message is there printed on a narrow tape, and this is then pasted on to a telegraph form.

At the present time it is the simple Morse sounder that is in general use both here and in the United States for all ordinary messages, but in order to cope with long press messages, etc., it is necessary to send the signals at a greater speed than can possibly be done by hand. For this purpose an automatic transmitter has been long in use. At the sending station a long paper ribbon or tape is first of all prepared by an operator using a perforating or punching machine. Small holes are punched in this

paper ribbon to represent the Morse signals. The perforating machine has three levers or keys; one key punches holes to represent short clicks or "dots," another punches holes to represent long clicks or "dashes," while the third key represents a letter space. When the Morse signals of a message have been prepared on this perforated tape, it is then run through an automatic sender, which makes and breaks the battery circuit far more quickly than any operator could do by hand. The perforated tape is run through this transmitter by clockwork, and is able to transmit, in one minute, signals representing as many as from two hundred to four hundred words. What is happening at the receiving end? Who can hope to decipher signals coming in at the rate of about seventy clicks in every second? Such a task is, of course, beyond the power of the most expert operator. It is a human impossibility. A special receiving apparatus is therefore required, but this can be very conveniently arranged. It is only necessary to cause the end of the little lever in the Morse sounder to make a mark on a paper ribbon each time the lever is actuated by the electro-magnet, and thus leave a permanent record of its rapid up and down movements. We therefore place a small wheel on the free end of this lever, and allow the wheel to rest in a little well of ink. When the other end of the lever is attracted down by the electro-magnet, this small wheel is raised against a paper ribbon, which is being moved along at a constant speed by clockwork. As long as the little wheel is kept against the moving paper a line will be marked along its centre, so that by making and breaking the battery circuit this little wheel can be caused to make long or short strokes along the centre of the paper. In this way the movements of the automatic transmitter at the sending

end are recorded at the distant station by this little Morse-inker.

It is, of course, possible to send signals by an ordinary hand key to the distant Morse-inker, but no advantage is gained, for in this case the receiving operator is quite as able to translate the clicks into letters as the sending operator is to transform the letters into the Morse signals. The automatic transmitter and its distant companion the Morse-inker are of very great service in connection with the quick despatch of press messages, etc. But for the invention of these instruments the Post Office authorities would require to have far more long telegraph lines connecting important centres.

There have been many very ingenious inventions in connection with high-speed telegraphy, but the simple Morse-inker still holds the field, its very simplicity being its advantage. By one of these recent inventions the receiving apparatus writes the message in ordinary characters at the almost incredible speed of forty thousand words per hour. Two hundred thousand letters of the alphabet in one hour! A tiny mirror, the movements of which are under electrical control from the distant sending station, throws a spot of light on to a sensitised photographic paper. This spot of light traces out the letters of the ordinary alphabet. When the paper is chemically developed, which process is automatically done by the receiving instrument itself, the message upon the paper may be read by any person. The advantage of having the message in ordinary writing is practically lost, however, as far as press messages are concerned, for it is necessary at the receiving end to make out manifold copies of the message for distribution to the different newspaper offices, and an expert operator can decipher the Morse code practically as quickly

as the writing of this special telegraph. The object of this machine is to attain a high speed, so that a sending tape is prepared to control the battery current.

There are many other forms of telegraph apparatus, but I shall only mention one other at this point. Many readers may have seen at one of the exhibitions or elsewhere a very interesting form of hand-writing telegraph. The sender writes his message upon a sheet of paper with an ordinary pencil which is attached to two light levers. The motion given to these levers is electrically transmitted to the distant receiving instrument, where a pen, controlled by two similar levers, traces out the letters made at the sending station. This apparatus has a distinct advantage over ordinary telegraph instruments in being able to reproduce a picture or sketch of any kind made at the distant station. It can also reproduce a signature in exact duplicate, and it has been suggested that one might sign a cheque, distant hundreds of miles, but one would require to have implicit confidence in the individual at the receiving end, that the transmitted signature was not being appended to anything but what the sender intended.

The construction and upkeep of long telegraph lines involves a heavy expenditure, so that the more messages that can be sent over a single line the more valuable that line becomes to the Post Office authorities. The automatic transmitter, however, is already sending the messages as quickly as can be ever possible; indeed, it is capable of making the dots and dashes faster than they can pass along the line if the distance be great. If we have the signals already following at each other's heels as close as they can get, what more can we hope to do? Send several messages at one time! It does seem impossible, and yet it is quite a common practice to send

four different messages over one single wire simultaneously. Two of the messages are travelling in one direction and the other two messages in the opposite direction. To make the matter quite clear we may picture four operators sitting together at the London end of a wire which stretches northwards to the Scottish capital, where four other operators are seated. Two of the operators at London are sending separate messages to two of the operators at Edinburgh, while the other two London operators are receiving separate messages from the other two Scotch operators. Four distinct messages travel over this one simple copper wire, and yet there is no confusion. I shall endeavour to give some idea of how this is accomplished, but to give a detailed explanation would necessitate a rather complicated diagram which I fear would only be a worry to the uninitiated.

What really happens is this, the two outgoing messages from the London end do not affect the two receiving instruments at that end at all. We may picture the two receiving instruments as being electrically shielded from the outgoing current. They are so placed in connection with the line wire that the outgoing currents have no inducement to pass through them, and as electricity will take the easiest path these currents make straight for the distant end of the line wire, a clear path being offered to them there. But why do the two receiving instruments at the distant end not attempt, each on its own account, to translate the two messages? The secret is that the two instruments are not the same, and the two sets of electric impulses sent out by the sending station are not the same either. The first operator at the sending end can only affect one of the distant receiving instruments, while the second operator is

sending a current which will only affect the other distant receiver.

Perhaps the best mental picture one can form of this "quadruplex" system of working, without learning all the detail of wiring, etc., is to think of a constant current flowing on the line, and the instruments so arranged that neither of them is moved by this current. If, however, there is any change made in the direction of the current No. 1 receiver is moved, but the other is not affected. No. 1 sending operator may therefore keep changing the direction of the constant current at will, and in this way send signals to No. 1 receiver at the distant end. To what, then, will No. 2 receiver respond? It is so arranged that it will move with any alteration in the strength of the constant current, so No. 2 sending operator must have a key by which he can alter the strength of the current at will, and in this way he can send signals to No. 2 receiver. The same arrangement is made between the two sending operators at the Edinburgh end and the two receiving instruments at the London end.

Many important lines are quadruplexed in this way, and every line of importance is at least "duplexed." The duplex system is just half of the quadruplex, there being only one sender and one receiver at each end. By the duplex system only two messages are sent simultaneously, one in either direction. We are indebted to the Austrian telegraph engineers for making duplex working a practical system, although we do not now use their original methods.

Several inventions have been patented, whereby a great number of messages may be simultaneously sent over a single line, but as none of these instruments are at present in every-day use, I shall merely mention the general principle of one such system in passing.

The idea in this case is to use telephone receivers in place of the ordinary telegraph instruments. As many as a dozen telephone receivers may be attached to the one-line wire, and each telephone may be arranged to reply only to the particular electric impulse, which will affect only this one and none of the others. That is to say, a particular electric impulse causes No. 1 telephone to hum a sound, while all the others remain silent; No. 2 has also a particular note of its own, and so on. It only remains to give each operator at the distant end a special battery key, which will set up the necessary rate of electric impulses to move one of the telephone receivers. Each operator can now work away on his own account, knowing that his signals will only affect one particular receiver at the other end. The signals used may be the ordinary Morse code, the telephone receiver giving long and short notes.

Returning to the ordinary telegraph business of to-day, we shall find many other points of interest.

At the larger telegraph offices all the instruments are supplied with current from a storage battery, the number of cells for any one line depending upon its resistance. The longer the wire the greater the resistance, and therefore the more pressure required to send the current through. In order to decrease the resistance on long wires, they are made of better conducting properties.

When an electric current is transmitted a long distance its strength is considerably reduced owing to the resistance of the wire, so that an electric impulse, on reaching a far-distant town, may not have sufficient energy left to cause the electro-magnet to attract the comparatively heavy armature required to make a distinct sound or to cause a recording instrument to impress the signals clearly on paper. This apparent difficulty is very easily

overcome, for as long as there is a very small current this will be sufficient to cause a small electro-magnet to attract a very light lever, and the movement of this lever can switch on a local battery to the telegraph instrument. This small electro-magnet and lever arrangement is called a "relay," or repeater, and when Morse signals have to be sent to long distances it is usual to place one of these midway between the stations. The relay is in construction identical with an ordinary Morse sounder, having an electro-magnet operating a small lever. This lever is so arranged that instead of the free end of the lever merely knocking against a stop, it thus completes an electric circuit and allows the current from a local battery to pass on to the line wire. That is to say, the current sent out by the distant operator merely operates this midway relay, which sends on a fresh current at each stroke, to the distant receiving instrument. The relay is in fact an automaton which imitates the movements of the distant operator. If he depresses his sending key, thus switching the battery current on to the line wire, then the relay at the "half-way house" moves its lever, and switches on its local battery current to the second half of the line wire.

With our climatic conditions in Great Britain it is not easy to send direct signals to a greater distance than four hundred miles, but the introduction of a repeater controlling a second battery helps us out of the difficulty. With the high-speed signals sent out by the automatic transmitters it is found advisable to introduce a repeater at every two hundred miles. On trying one long line, without any repeaters, the Post Office authorities found that the highest speed at which the direct line would carry the automatic signals was one hundred words per minute; but by introducing one repeater on

the way, it was found that the speed could be increased to four hundred words per minute.

There is a further use for the repeater. London has daily news arriving from abroad, and it is necessary to distribute this to all important towns. Much of the news for each town is identical, so that it is very convenient to run one single wire through a number of large towns, each town receiving the signals and at the same time operating the next section of the line. For instance, a line is run from London through Leeds, Newcastle, Edinburgh, Glasgow, Dundee, and Aberdeen, and in this case it is not necessary to put a repeater at each town, there being only one at Leeds, and another at Edinburgh. All these towns receive the news simultaneously from one automatic transmitter in London.

To be able to operate a light relay by sending a weak current is a most convenient arrangement for many purposes, for we can thus control, from a distance, the current of a more powerful local battery.

The Morse system of telegraphy is likely to hold the field until displaced by some simple and reliable form of typewriting telegraph. The Morse alphabet is so easily learned, and the telegraph apparatus is so very simple. We are indebted to our American cousins for the Morse system, and it has quite displaced an English system set afoot about the same time.

It may be that some readers have been wondering where the necessary complete electric circuit is when only one wire is used to connect two distant telegraphs together. It was naturally supposed at the outset that a return wire was required, but one experimenter accidentally discovered that if the two ends of the wire were given a good connection with the earth, the circuit was as complete as though a return wire existed. As a

matter of fact, if a wire is erected, say, between London and some distant town, and at the latter place the wire is connected to a galvanometer, which will indicate the strength of an electric current passing over the line to it, it will be found that the current strength is much greater when the earth is used in place of a return wire. In order to picture this earth connection, we need not suppose that the electric current rushes back from the one end of the wire through the earth to the other end, for we may

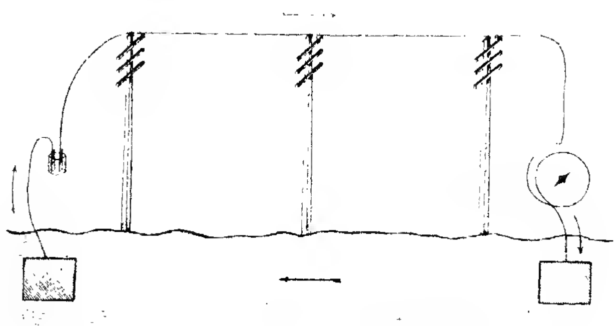


Fig. 6.—How a Telegraph is Worked with a Single Wire

imagine the earth to be as a great reservoir. We then picture the current being dissipated at the one end of the wire, and fed on at the other end, the battery acting as a pump. In order to get a good earth connection it is necessary to attach the ends of the wire to large metal plates, which are sunk in the moist subsoil, or if the wires be attached to water-pipes, etc., the result is the same. (See Fig. 6.)

In the smoke-rooms of many of the large hotels and clubs in London one finds a very compact little instrument busily engaged printing off the news of the day on a

long sheet of paper. A little wheel carries the letters of the alphabet in rubber type upon its periphery. This wheel spins round and stops in any desired position, then quickly moves forward and prints the letter on the paper. The necessary energy is supplied by clockwork in the instrument, but its actions are electrically controlled from a distant sending station. The controlling current is operated by keys similar to those of a piano, so that the sending operator does not require to learn a code, while any person can read the message, printed by the little revolving wheel in ordinary Roman type, at the receiving end. It is interesting to watch the little type-wheel at work. After spinning round at a very rapid pace and stopping with the desired letter in position, it impresses it on the paper and then moves along the space of a letter, or if at the end of a word it makes two steps to the right. When it reaches the end of a line it springs back to the left-hand side of the paper once more, while the paper is rolled up to bring it in position for the next line.

While this instrument serves a very useful purpose in distributing important items of news to hotels, etc., it is not considered equal to the demands of the Post Office as a type-printing telegraph. So far any page-printing telegraph instrument has been either too complicated in its mechanism, or not sufficiently reliable in its action, to warrant its adoption by the Post Office for ordinary work; but many inventors are at work upon the solution of this interesting problem.

CHAPTER V

HOW CABLEGRAMS ARE SENT

A difficulty in transmitting cablegrams—Early attempts at submarine signalling by the Royal Engineers—The advent of gutta-percha and its great assistance—Some interesting facts about the laying of the first Atlantic cables—How the messages are signalled and recorded—Discovering and repairing faults—The work of Lord Kelvin as chief electrician and of Sir Charles Bright as engineer-in-chief.

IN these days when the public keep crying out for reductions in the prices charged for sending cablegrams abroad, the methods by which cablegrams are transmitted should be of special interest.

The man in the street may think that when once a submarine cable is laid there is no more difficulty in sending telegrams by it than there is on overland routes. We should agree with him as regards short distances, such as from England or Scotland to Ireland, and therefore we find no extra charge made for such telegrams, which are really cablegrams, having to cross the Irish Sea by means of a submarine cable. But while these short lines can be worked with ordinary Morse-inkers, it is quite impossible to use them on ocean cables. If we could stretch an overhead line in the air from our shores to lands across the sea, and if we could place repeaters at convenient distances, we should have no difficulty in using ordinary telegraph instruments. When, however, it is necessary to enclose the wire in a

thickly insulated covering, the conditions are very different, as we shall see later.

Although the first ocean cables were laid more than half a century ago, the story of the gigantic undertaking is well known to most of us. However, it may be of interest to note very briefly the outstanding facts.

It is interesting to find that one of the very first practical attempts to conduct an electric current along a wire under water was made by an officer in the Royal Engineers. Colonel Pasley, who afterwards attained the rank of major-general and was knighted, made these early experiments in the Medway, at Chatham, and also in connection with the submarine operations on the sunken wreck of the ill-fated *Royal George* in Portsmouth harbour.* The plan adopted by Colonel Pasley was to bind around the wire several strands of tarred rope, and on the top of that covering another of pitched yarn. While such methods served a useful purpose, there could be no real and permanent success attained until gutta-percha came into use. This substance was introduced into European arts about 1843, and a few years later it was found that gutta-percha might be used as an electric insulator.

Gutta-percha as well as being a good insulator is also very pliable and easily handled. The copper wire encased

* It will be remembered that this British man-of-war, when under repair in Portsmouth harbour, was heeled over to enable repairs to be made near the keel, and water rushing in at the portholes of the depressed side, the vessel went down suddenly with all who happened to be on board. Out of the eleven hundred people only two hundred were saved. We are, no doubt, all familiar with Cowper's elegy on the loss of the *Royal George*. Although this calamitous event happened in 1782, the operations mentioned above were not made till 1839, when the mass of the wreck was blown to pieces, after all valuables had been removed.

in gutta-percha is all that is required as far as the electrical properties of the conductor are concerned, but the cable must be able to stand some pretty severe handling in the laying of it, and it must also be equal to the strain put upon it by strong tidal currents, etc. The cable must therefore have a strong outer casing or armouring as a protection for the conductor and its insulating material. This is supplied by a sheathing of iron wires twisted round and round on the outside of the insulating material, and giving the finished cable an appearance similar to that of an ordinary wire rope. Before the iron sheathing is wound on, the gutta-percha with its enclosed conducting wire is very carefully wrapped in cotton tape and soft cotton yarn, then a strip or ribbon of brass is wound spirally over that, and again more cotton tape and a layer of tarred hemp. On the top of all these comes the iron wire protection, which is also well tarred.

Early cables contained one single copper wire to act as the conductor, but it was soon found better to make the conductor up of seven separate strands of copper wire, for there was then less risk of a total break of the conductor from any overstrain. As there is considerable expense in manufacturing the protective part of the cable, it naturally occurs to one that it would be an advantage to enclose several sets of insulated conductors inside the one armouring, and thus supply connections for a number of telegraph instruments. This cannot be done in long cables such as the Atlantic ones, for the electric current sent along one wire would induce a similar current in the neighbouring conductors. For shorter cables, however, such as those across the North Sea, as many as four separate conductors are placed in the one cable, and for very short distances, such as

across rivers, as many as twenty conductors may be enclosed inside the one sheathing.

While only one conductor can be enclosed inside an Atlantic cable, it is possible to "duplex" the line, as described in the preceding chapter. There is then a sending and a receiving operator at each end, so that the cable is carrying messages simultaneously in each direction over the one conductor.

When one thinks of the very great difficulties connected with the laying of the first Atlantic cables, how one attempt after another had to be made, one can well understand the great interest and excitement evinced both here and in America, when at last, in the autumn of 1858, the first telegraph message was successfully sent across the great Atlantic. After a short but busy life of three weeks this pioneer cable became quite dead. It had carried over seven hundred messages, but had never been opened to the public for business. All attempts to repair it proved hopeless.

It was eight years before another telegraph message crossed the Atlantic, in 1866. In the previous year the second cable was laid, but it parted in deep water after about two-thirds of it had been successfully submerged, and the engineers were forced to abandon it. However, after the 1866 cable had been successfully laid, it was found possible to pick up the end of the 1865 cable and complete it also. Although these were the earliest Atlantic cables, many shorter ones had been laid in other places, there being about one hundred submarine cables in existence by 1866. It really took more than a year to lay the first Atlantic cable, but having gained by the experience and difficulties of these early pioneers, we can now lay a complete cable across the Atlantic, from Ireland to Nova Scotia, in less than three weeks'

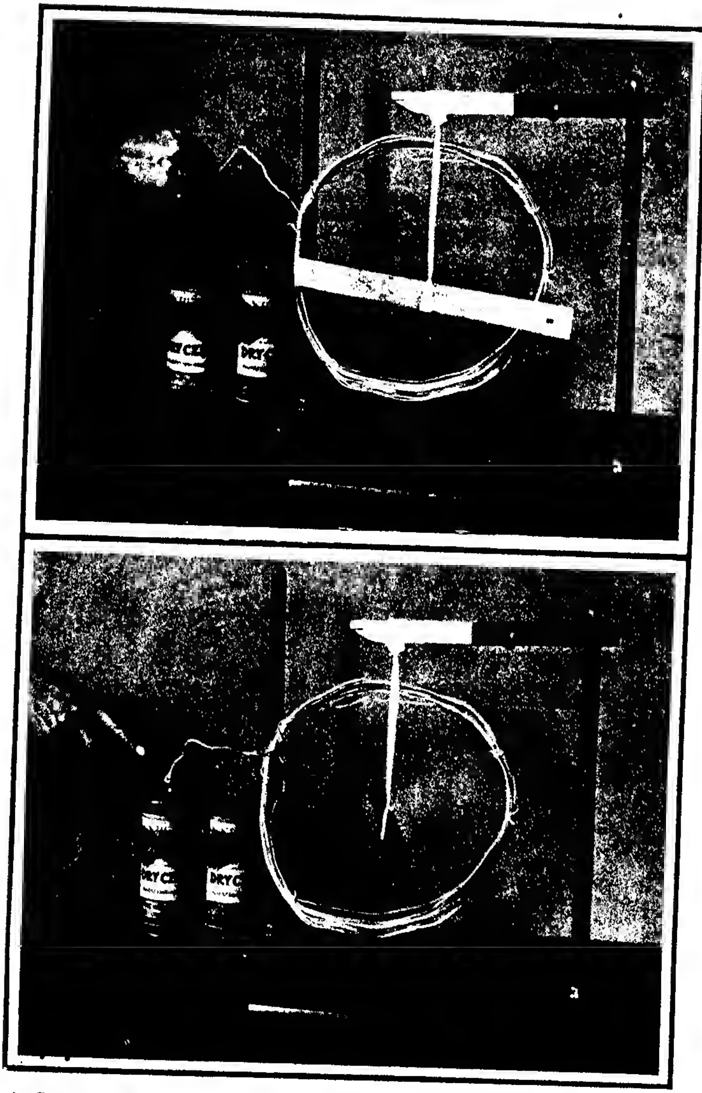
time. These three pioneer cables are now lying dead at the bottom of the ocean, but they have indeed served a useful purpose. We have now from fifteen to twenty cables carrying intelligence between Europe and America. Not only is the Atlantic spanned; submarine cables are laid in the Pacific, the Mediterranean Sea, the Black Sea, the Arabian Sea, the Indian Ocean, the North Sea, the English Channel, etc.

The great irregularities in the depth of an ocean make cable-laying a very difficult task. Although the average depth of all the oceans is about two and a half miles, a depth of over seven miles has been found in the South Atlantic, and about five miles in the North Atlantic. A cable ship will be laying a cable at a depth of one mile below the sea's surface, when it finds that this is the top of a great submarine mountain, and, as the ship continues to lay the cable down the mountain side, it soon becomes apparent that this mountain is two and a half miles in height, for the cable is found to have reached a depth of three and a half miles below the surface of the sea. A cable ship keeps in constant communication with land, through the cable it is laying, during the whole voyage, so that those on board hear of any important event occurring on land in their absence.

In the opening sentences of this chapter we noted that the ordinary telegraph instruments are of no use in connection with long cables. The reason for this is that an insulated cable behaves quite differently from an ordinary bare telegraph wire. The cable becomes charged, somewhat like a Leyden jar, and thus retards the flow of the electric current. In order to obviate this, as far as possible, special condensers are used to assist the current, but even then the resulting current is not sufficient to move a delicate relay for a Morse instrument.

It was found necessary to have a much more sensitive receiver, although for short cables (such as across the Irish Channel, etc.) ordinary Morse-inkers are worked by the Post Office. It was by the inventive brain of Professor William Thomson (the late Lord Kelvin) that a suitable instrument was devised. The principle upon which this works is very simple, and is in point of fact the same as already described in the needle telegraph. It will be remembered that the current passing in a coil of wire caused a magnetic needle to swing round. In this more delicate apparatus a very tiny magnet is suspended by a silk fibre, inside a small coil of very fine wire; but as a small movement of this little magnet could not be easily seen, there is attached to it a tiny mirror, which along with the magnet weighs only about a single grain. A lamp throws a fine ray of light through a slot in a screen, and this, falling upon the mirror, may be reflected upon the wall or upon a graduated scale. By this ingenious method a very small turning of the tiny magnet gives a large motion to the spot of light, as every boy who has annoyed his neighbours with a small sun-reflector will well understand.

It became rather tiresome to the eyes watching this spot of light dancing to and fro, indicating the Morse signals, a movement to the one side signifying a "dot," and to the other side a "dash." It therefore occurred to Sir William Thomson that he might cause the tiny magnet to move a pen across a paper ribbon and thus leave a record of its deflections to left and right. To the ordinary man this would seem an impossible task. The mirror galvanometer was so very delicate it surely could not be expected to move a pen. It certainly could not move a pen of any ordinary make, but Lord Kelvin used a very small glass tube, which could be rocked to



A Coil of Wire carrying an Electric Current behaves like a Magnet

In the upper illustration the battery is not connected to the coil. When the circuit is completed the large steel magnet swings round and takes up a position at right angles to the face of the coil, as in the lower photograph.

one side or the other by silk fibres attaching it to the little magnet. This little glass tube was made to act like a siphon, its one end dipping into a small well of ink, and the other end placed immediately over a paper ribbon, which was moved along at a constant speed by clockwork, just as in the Morse-inker, described in the preceding chapter. In order to make a constant stream of ink pass from the tiny siphon on to the paper, it was found necessary to electrify the ink, by means of a small static machine. Later it was found that by giving the little siphon a vibratory motion a similar result was obtained. The little siphon while in its normal position would mark a straight line along the centre of the moving paper ribbon, but if an electric current reaches the coil of wire, the current being sent from the other side of the Atlantic, then the little siphon will be rocked to one side or the other, according to the direction in which the current is sent around the coil. In this way the movements of the little magnet to left or right are traced out on the paper ribbon, appearing as curves above or below the central line when reading the paper lengthwise, or if the ribbon is turned round, as in Fig. 7, the right and left movements of the needle alphabet may be seen.

In describing the siphon recorder I have, for the sake of simplicity, imagined the glass siphon to be controlled by the tiny permanent magnet of the mirror galvanometer, but in practice the construction of the instrument is different, although the principle involved is identical. In order to get as much advantage as possible from the incoming current the order of things is reversed. In the mirror galvanometer we have a small permanent magnet controlled by a weak magnetic field produced in the coil of wire by the incoming current.

This is sufficient to cause the tiny magnet and its mirror to turn round, but these together only weigh about one single grain. This effect will not be sufficient to satisfactorily move the glass siphon. Therefore, instead of depending upon a weak permanent magnet to be controlled by a weak magnetic field set up by the incoming current, there is a powerful magnetic field permanently produced by a large stationary steel magnet, and between the poles of this magnet is suspended a

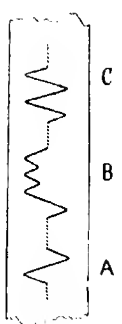


Fig. 7

light coil of wire which becomes a magnet whenever the incoming current traverses it. This coil is then attracted by the poles of the stationary magnet according to the direction in which the current is passing round the coil. In this way a more energetic movement is obtained from the incoming current, and the siphon is satisfactorily rocked to one side or the other.

The invention of these sensitive telegraph instruments by Lord Kelvin is of historical importance, for it would have been quite impossible to have sent intelligible

signals over long submarine cables by any ordinary piece of mechanism.

A modern cable will transmit messages at a rate of about fifty words per minute, which is twice as much as could be accomplished on the early cables. Automatic transmitters are used on all long cables, the advantage gained being not so much a matter of slightly increased speed, as a regularity of signals which cannot be given by hand.

Having once laid the cables, the expense of carrying on the business does not only mean the working of the apparatus on land, for a whole fleet of large steamers is required to maintain the cables in perfect working order. When a fault occurs, its position can be determined by testing the cable, and noting how much resistance is offered to the passage of an electric current. The exact resistance offered by one mile of the cable is known, so that the length through which the current is going, before escaping to earth at the faulty place, can easily be determined. A steamer then proceeds to this point, and rakes the bottom of the ocean with a grapnel until the cable is caught, possibly at some little distance from the fault. It is then brought on board and cut, and when tested one or other of the ends will enable messages to be got through to land. This end being found to be quite sound, is sealed up and dropped overboard with a large buoy attached. The other end is gradually picked up, and it may be found to be quite severed from the main part of the cable. If so, then the other end of the cable has to be picked up as already explained. Then a fresh piece of cable is spliced on, and tested through to land, the steamer having thus got in touch with both shores. The steamer makes her way back to the floating buoy, paying out fresh cable

as she goes. It only remains to make the final splice, and the cable is once more complete from shore to shore.

It has happened that a dead whale has been found entangled in a faulty cable, and on one occasion when raising a faulty cable in the North Sea, the repairing steamer brought to the surface a small sailing vessel. The teeth of sea-monsters have often been found embedded in faulty cables, but the chief enemies of the cable companies are small marine insects or worms, which can slip in between the wires of the outer sheathing, and bore their way through the insulating cover, thus causing a leakage. These marine organisms are like soft-bodied snails, some being about the size of a pin's head.

In the early days of ocean telegraphy it cost twenty pounds to send a message across the Atlantic, the charge being one pound per word and the minimum number of words allowed being twenty. We can now send messages of any desired length at the rate of one shilling per word, and by using a telegraphic address and a single code word quite a lot of intelligence may be sent. Allowing two words for the telegraphic address and one code word for the message, the total cost is three shillings. Several standard codes exist, but business houses often arrange special codes of their own, while any person may arrange a temporary code with a friend. By such means a single word may mean a great many words, and it is recorded that on one occasion a message was sent in which one word stood for a pre-arranged message of two hundred words.

While the name of Sir William Thomson, afterwards Lord Kelvin, stands out very prominently in connection with the first Atlantic cables, it should be noted also

that a great deal of the ultimate success in laying the cables was due to the ingenuity and skill of the late Sir Charles Tilston Bright, who designed and supervised the working of the paying-out machinery. As engineer-in-chief, Bright had many difficulties to contend with, and although only twenty-six years of age at that time, he successfully overcame all these.

CHAPTER VI

SIGNALLING WITHOUT WIRES

Wireless telegraphy has a special sphere—Communicating by vibrations—The medium of communication—The origin of wireless telegraphy—A simple explanation of the general principle—Coherers and other detectors—The different wireless systems—The problem of interference—How tuning is obtained for a selective system—The antennæ—The source of power for transmission.

NEEDLESS to say, it is a very great advantage to be able to signal to a distance without first of all requiring to establish a material conductor.

Visible signals are all right for short distances, provided the atmosphere is clear. It is not so very long ago (about 1830) that our Government thought the semaphore system to be the last word in space signalling. When the early experimenters in electric signalling approached the Government in connection with this matter, the authorities informed them that "telegraphs of any kind other than those now in use are entirely unnecessary, as the Government are fully satisfied with the semaphore system." It is clear that the authorities did not appreciate the possibilities of electric signalling.

Although wireless telegraphy is no longer in its infancy, but has passed out into the business world, there are many intelligent people, who, unfortunately, look upon it as a mere scientific toy. One of the leading experts in wireless telegraphy has mentioned this grievance to me on more than one occasion. Our chief concern, however, is to see clearly the means by which the present undoubted success has been attained.

Signalling Without Wires

Wireless telegraphy has a special field of its own; it gives us a means of communication in circumstances in which no other method can be of any service whatever. We can signal to ships far out at sea, even although we have no knowledge of the exact whereabouts of the ship. Ships which are not within sight of one another can establish communication with each other. Whether or not wireless telegraphy will compete seriously with submarine cables remains to be seen, but some of the wireless companies are making a big bid for transatlantic signalling. Wireless telegraphy may be used on land, but here it comes into competition with ordinary telegraphy, which has distinct advantages. There is one direction, however, in which wireless telegraphy may prove of inestimable value on land, and that is in times of war. It is obvious that if each division of the army can keep in touch with the head-quarters and receive instructions and guidance, a very great advantage has been gained. The enemy cannot cut their line of communication in wireless telegraphy.

When one person speaks to another the speaker merely sets up certain vibrations in the air, and these so stimulate the hearing apparatus that a series of nerve impulses are conveyed to the sensorium, where the meaning of these signals is unconsciously interpreted. In wireless telegraphy the sender sets up vibrations, not in the air, but in a something which we call the all-pervading ether, and these ether vibrations reaching to a great distance so affect a receiving apparatus that signals are made, and the operator watching the movements of the receiver may interpret the signals.

For the present we shall be content to know that there is a something which fills all space, that scientists have named it the ether, and that it is the medium for

conveying light, heat, and electricity. It is this medium which conveys energy from the far distant sun to us, and it has been possible to calculate the speed of travel of the ether vibrations which we call light. The speed is not much short of 200,000 miles per second, or to be more exact, 186,400 miles in one second.

When the ancients sent messages across the country by means of beacon fires, how were the signals transmitted? These ancients were using the same medium as we do in wireless telegraphy. The burning fire set up ether vibrations, and these so affected the eyes of the distant watchers that they received certain sensations, which by experience they recognised as being caused by a bright light at a distance. It had been pre-arranged that when this fire was set alight it would have a certain meaning, and so the signal could be interpreted.

Just as the ear is the receiver of air vibrations, so is the eye the receiver of ether vibrations. The ear can only detect a limited range of air-vibrations; the eye can only detect a limited range of ether vibrations. If we wish to send a signal by light to a distance, we must use a powerful source of light, so that we may cause a considerable disturbance in the ether; the same principle applies to wireless telegraphy. But how are we going to disturb the ether so that signals may be carried to a very great distance? It is certainly not by producing the rates of ether vibrations which come within the limited range recognisable by the eye. There are other disturbances in the ether as well as those we call light. We have seen that there is an ether disturbance around a wire carrying an electric current, for when a magnetic needle is placed within the area of this disturbance the magnet is moved bodily into another position. This we call an electromagnetic disturbance in the ether. Again, if we give an

insulated body a charge of electricity, we find that any light object brought near to it is suddenly attracted, indicating a decided disturbance in the ether, which is described as an electro-static disturbance or effect.

The present system of wireless telegraphy is dependent upon this electro-static disturbance of the ether. It originated from some experiments made by thé late Dr. Hertz, of Carlsruhe (Germany). Hertz was endeavouring to prove experimentally the celebrated electro-magnetic theory of light, as formulated by Clerk Maxwell some twenty years previously. Up to this time, about 1886, electric waves were known only in theory. Mathematicians had devised means by which the lengths of such waves might be calculated. Their nature and behaviour had been predicted, but the experimentalist could find no means of detecting these electric waves, which were known to exist in the ether when any sudden electrical discharge took place. Hertz discovered a method of doing so. He set up the waves in the ether by means of an electrical discharge from an induction coil; he believed that each time a spark discharge occurred the surrounding and illimitable ether was disturbed. How could these electric waves be detected? One might expect to hear of some very ingenious and sensitive piece of apparatus, so arranged that it would be affected by these imperceptible waves. Instead of this nothing could be simpler; a short length of wire with a small brass knob at each end, and the wire bent round to form almost a complete circle, leaving only a small air gap between the knobs, and that is all. This very simple arrangement enabled Hertz to detect the ether waves set up by the induction coil. Each time there was a spark discharge from the induction coil Hertz found a small electric spark also occurred between the knobs

of his simple wire loop, which was held at some distance away from the induction coil. It has been proved beyond any possible doubt that electric waves were propagated through the ether.*

It was very soon suggested by several scientists that these electric waves might be used as a means of transmitting signals to a distance without any connecting wires. The scientist did not, however, consider at first that these electric waves could be conveniently used on a large practical scale for ordinary commercial purposes. The discovery of a detector which would record the passage of an electric current of extremely short duration, such as is induced in the receiving circuit by the radiation from a Hertz oscillator when a spark occurs, gave an impetus to the idea of space telegraphy. It had been observed by an experimenter on the Continent that while loose metal filings offered a great resistance to the passage of an electric current through them, this resistance was very materially reduced when electric waves fell upon the filings, and that it remained so until the filings were shaken, thus giving time for the effect to be observed in an ordinary telegraphic instrument.

The general principle of wireless telegraphy will be understood by reference to the simple arrangement in Fig. 8, and the legend accompanying it.

The tube of filings has been named a "coherer," signifying that the filings cohere or cling together under the influence of the electric waves. The tube may be made of glass, or any other insulating substance. One

* It is interesting to note that Professor Sylvanus Thompson, of London, made a very similar experiment as early as 1876. He showed that electric sparks occurred between two ordinary door-keys when placed close together and taken to some distance from the induction coil apparatus But Professor Thompson has said: "It never dawned upon me that these sparks were the evidence of electric waves crossing the space."

wire enters at each end of the tube, and each is attached to a small block of metal. These two blocks are brought very close together, and then the small space between them is very loosely filled with fine metal filings. Any metal will do, but it has been found that nickel filings

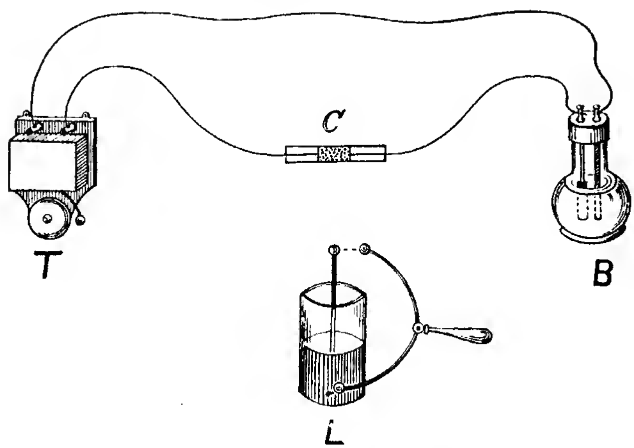


FIG. 8.—THE PRINCIPLE OF WIRELESS TELEGRAPHY

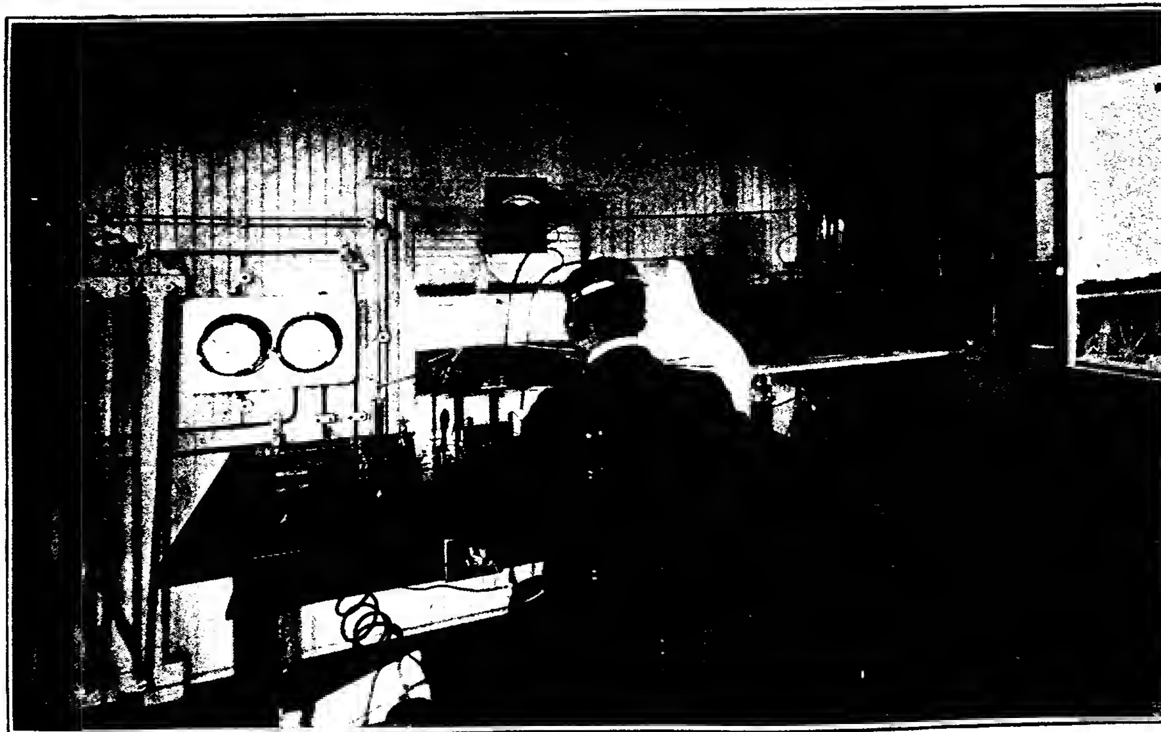
The current from the battery (B) cannot get to the trembler bell (T) because of the resistance offered by the coherer (C). When an electrical discharge takes place from the Leyden jar (L) ether waves go out and induce a momentary voltage in the wires connected to the coherer, thus reducing the resistance of the filings in the coherer, allowing the current to pass to the bell, thereby causing it to ring. If the gong-stick is so arranged that it strikes the coherer at each movement, the jolting serves to "decohere" the coherer, and thus break the circuit once more.

with a trace of silver act very well. An apparatus such as described, with a simple bell, would not make a very convenient telegraph apparatus, but with the aid of a relay we may connect a Morse sounder or inker to the coherer.

Many different forms of detectors have been invented, but they all have the same duty to perform: to close a local battery circuit when electric waves fall upon the detector. Marconi improved upon coherers, and along with his assistants he developed other methods of detecting the electric waves. It was Marconi who put wireless telegraphy upon a business footing.

One very good form of coherer, used by the Italian navy, consists of a glass tube with small carbon blocks or plugs attached to the ends of the wires, and instead of metal filings there is a bead or globule of mercury between the plugs. When electric waves fall upon this coherer, the mercury coheres to the carbon blocks, and thus forms a bridge for the battery current. One advantage in this form of coherer is that it does not require to be mechanically shaken to break down this bridge, for the mercury will only cohere to the carbon plugs as long as the electric waves are affecting it. In other words, the mercury tube decoheres of itself immediately upon the cessation of the electric waves. Instead of connecting this mercury tube to a telegraph instrument, it is usual to place a telephone receiver in the circuit, for the current does not last long enough to work any other instrument. Each time the tube coheres there is a soft hum or buzzing sound heard in the telephone, and it is a simple matter to signal the Morse code by short and long sounds. This coherer is very sensitive, and has been used over very long distances.

As the coherers already mentioned show how electric waves may be detected in wireless telegraphy, there is no need to do more than merely mention one or two other forms of detectors. The necessary loose contact is got in one coherer by a pointed carbon resting on a slightly oxidised steel surface, while a somewhat similar plan



By permission of] WIRELESS TELEGRAPH STATION [*National Electric Signalling Co., U.S.A.*

The operator is receiving a wireless message from a distance. He hears the clicks in the telephone, and is busy writing down the signals as they arrive.

is to have a lead electrode resting on a surface of peroxide of lead. Another very sensitive detector is obtained by a revolving disc touching lightly on a column of mercury, which has on its surface a thin film of mineral oil. All these different inventions come under the heading of coherers, but there are others in which the action is just the reverse, and which therefore go by the name of anti-coherers. One anti-coherer consists of a tube similarly arranged to the ordinary filings tube, but with two little blocks or rods of tin between which there is placed a semi-liquid paste, sometimes composed of alcohol with tin filings and lead oxide. This paste in its normal condition allows the battery current to get across from the one block to the other, but when electric waves fall upon it they produce a chemical action which immediately breaks down this bridge and stops the current. Upon the cessation of the electric waves the paste at once returns to its normal condition and allows the battery current to again pass. The signals are therefore a sudden breaking and making of the battery circuit. If a telephone receiver is connected to the tube and battery, it will be very easy to tell when the battery circuit is broken, for there will be quite a loud click heard in the telephone. Any person using the ordinary telephone may hear the click referred to by depressing the telephone hook or support while the receiver is held to the ear. When the hook or support is depressed the battery current is cut off from the telephone, and it is this stopping of the current causing a sudden change in the magnetic field of the receiver which produces the click. This will be better understood when we come to the explanation of the telephone in the following chapter.

The wireless telegraphist has not only invented sensitive coherers and anti-coherers; he has constructed other

entirely different forms of detectors. The most prominent of these is the magnetic detector. To understand this invention we must keep in mind that if a piece of soft iron is continuously revolved in front of a permanent magnet, the magnetic poles of the soft iron piece will keep changing their position at each half revolution. This magnetic change requires a little time to take place, so that the change somewhat lags behind the magnetising force as it were, or perhaps it is better to picture a certain resistance being offered to this change of magnetic poles. It was discovered that if electric waves fell upon the iron this resistance was almost entirely eliminated, so that the magnetic poles could then change places instantly as it was revolved. If we have a quickly changing magnetic field, then, it will induce or set up an electric current in a neighbouring coil of wire. In this way we can detect the changes in the magnetic field, for we can place a telephone receiver in connection with the coil of wire just described. In a modern receiver of this class it is found more convenient to replace the revolving iron piece by an endless band of soft iron wire. This band is kept passing in front of a permanent magnet, the magnetism of the wire tending to change as it passes from the one pole to the other. This change takes place suddenly when the electric waves from the transmitting station fall upon the receiving aerial conductor and are conducted round the moving wire, and as the band is passing through a coil of insulated wire attached to a telephone receiver, this sudden change in the magnetic field induces an electric current in the surrounding coil and the operator hears a sound in the telephone which he has at his ear. The Morse code may thus be signalled from the distant transmitter.

After describing the first coherer with the metal filings,

I said that the duty of all detectors was to control a local battery circuit, but this magnetic detector just described is an exception to the rule. Here we have no local battery as used with the coherers and anti-coherers. Are the incoming electric waves, then, supplying the necessary energy to operate the receiver? No! They are still merely acting as a controlling force, for we are supplying energy by moving the iron wire in front of the magnet, and the ether waves from the distant station are merely changing the resistance of the iron wire, so that it may be suddenly magnetised and demagnetised. It is true we have not supplied electrical energy by means of a local battery, but have we not supplied it by a miniature dynamo instead?

There is another class of detector which I think will be of special interest; indeed, the controlling of these detectors by men distant hundreds of miles from them, and without any connecting wires, seems more like fiction than fact. This detector, which is the last I shall mention here, is dependent upon the fact that, when a rapid to-and-fro or oscillating current surges in a wire, there is a distinct heating of the wire. When the temperature of a wire is increased its electrical resistance also increases, so it only remains to detect this change of resistance in a similar manner to the detectors already described. When a body is heated it takes an appreciable time to cool down again, so how is the wire in this detector to be got ready for a second signal? This is accomplished by making the whole length of the wire that is to be heated of very small dimensions. The wire used for this purpose in the receiver, or "barretter," as it is called, is not as big as a pin's head; indeed, it only measures one-thousandth part of an inch in length, and about one twenty-five-thousandth part of an inch in

diameter. How can it be possible to make a wire of these tiny dimensions? First of all a silver wire is made with a platinum core, and this wire is drawn out till a total diameter is about one five-hundredth part of an inch, while the inner core of platinum only measures one-fiftieth of this, or about one twenty-five-thousandth part of an inch. It only remains to lay bare a tiny speck of the inside core, and this is easily accomplished by bending the wire into a loop, and then dissolving the silver off the very tip by immersing it in a strong acid. When the current surges to and fro in this conductor it will only heat the tiny speck of exposed platinum, for it will have an easy path in the silver wire on either side; just as we find in the case of electric lamps that the conducting wires do not become heated, but that the same current raises the fine carbon filament to a white heat.

Sufficient detail has been given of the various forms of wireless receivers to show that the ground already covered by inventors is very extensive. In describing the different detectors I have purposely omitted the names of the inventors, in order to simplify matters as much as possible; but as one so often sees references in the daily papers and journals to the different systems by name, it may be of interest to briefly mention the more important of these.

The Marconi system includes many forms of coherers, also the magnetic detector, and many variations of these. The Lodge-Muirhead system, while employing similar coherers, has the revolving disc and mercury contact as its own special detector. Formerly one sometimes read of the Slaby-Arco and the Braun-Siemens systems, but these two German couples are now combined together under the Telefunken system. This odd-looking word

really means spark-telegraphy. The special feature of this system relates to the methods adopted for sending out the electric waves. There are two American systems very often mentioned, the De Forest and the Fessenden. The electrolytic detector with the paste between the tin blocks belongs to the De Forest system, while the barretter with the speck of platinum wire is one of Professor Fessenden's inventions. There are many other names well known in connection with wireless telegraphy —Popoff, Jackson, Armstrong, Orling, Dolbear, Stone, Artom, Lepel, and Poulsen, being but a few of these.

If one pictures a number of wireless stations at work, simultaneously sending out ether disturbances, it does not require a very vivid imagination to predict that there will be a possibility of interference between the different stations. How will a certain receiver know which particular set of electric waves to respond to? This trouble does exist, and indeed it forms the most important problem to be solved by wireless telegraphists. In the early days this trouble was very marked. It was quite a common thing at the outset for the receivers of one system to reply to the transmitters of a rival system. This trouble has in a certain measure been overcome, in some cases with considerable success, but there is evidence that the trouble has not yet disappeared. The British Post Office authorities have refused licences to some applicants seeking permission to erect wireless stations at certain points around our coast, on the ground that there would be a risk of interference between the proposed station and some other system already licensed in the same district.

The interference difficulty is overcome, as far as possible, by "tuning" the instruments. If we can cause a transmitter to set up a definite rate of vibrations in the

ether, and arrange a receiver which will respond to that particular rate of vibration alone, then we have a selective or tuned system.

In order to tune the instruments, we must first of all control the electric waves sent out by the transmitter. We must arrange a definite rate of vibration. This could not be satisfactorily done with the early arrangement, which consisted in merely storing up an increasing electric pressure by means of an induction coil, until the insulating air gap was forced to break down, whereupon a sudden discharge took place accompanied by a spark. This was analogous to drawing back a flat metal spring, and suddenly letting it go with a bang. There would be a certain oscillating motion given to the spring, but the bulk of its energy would be spent in the first one or two impulses. This system of transmitting ether waves has been descriptively named by some "the whip-crack method." To use still another figure, this system is analogous to making a sudden splash in the ether ocean, whereas we require to set up a series of rhythmic ripples to have a tuned system.

If wireless telegraphists had got no further than their first system of transmitters there would have been little hope of commercial success. The tuned transmitter sets up a regular set of definite oscillations in the ether. The electrician understands the method of tuning wireless instruments, when he is informed that the capacity and inductance of the receiver must be the same as those of the transmitter.

What has been the practical result of tuning in wireless telegraphy? Two different receivers placed close together may simultaneously receive different messages from two separate transmitting stations. Again, picture one of our battleships with a tuned transmitter on board, while the

receiver corresponding with this transmitter is on another vessel five hundred miles distant. Messages are being sent out to the distant ship, and at the same time another differently tuned receiver on board the sending battleship is picking up messages from a third vessel within close range. This is an immense advance beyond the capabilities of the original untuned system. A receiving instrument is, of course, sheltered from the influence of the transmitter at its own station.

In order to set up as energetic electric waves as possible, there have been many methods devised at the transmitting stations. If we picture the two metal balls or spheres between which the electric discharge takes place, we can then think of a wire being attached to one ball and carried up into the air to a height of two hundred feet or more, while another wire is connected to the second ball and led to earth. One method is to erect a simple wire on a pole, another is to support a regular network of wires from strong steel towers built to a height of over two hundred feet. Sometimes the wires have been arranged like a great inverted pyramid, while one system employs a great sheet-iron tube, like a factory chimney, reaching a height of over four hundred feet.

It was only when one of the conductors in the transmitter was connected to earth that long distance transmission became possible. Only a few miles could be spanned by the true " Hertzian waves " previously used ; these electric waves called after Hertz were produced without any earth connection. Waves of this class would radiate out into all space, whereas those set up by a grounded transmitter, with the receiving instrument similarly connected to earth, would at least keep within the immediate neighbourhood of the earth. Many attempts have been made to direct these electric waves

and send them out in one particular direction, and some success has been reported.

In reading any account of the doings of wireless telegraphy one is sure to come across the word "antenna." Possibly one has previously fallen in with this word in connection with insects, whose tiny horns or feelers are called their "antennæ." The electrician uses this same word as being descriptive of his aerial wire or feeler at the receiving station. This aerial wire serves also for the transmitter, in which case it might be termed an emitter, but as the erection is common to both the transmitter and receiver it is convenient to let the word antenna simply stand for the aerial erection.

For distances up to about two hundred miles a storage battery and an induction coil are sufficient to produce the necessary ether disturbance, but where a greater distance has to be spanned, then a steam engine and dynamo are called into play in order to supply a greater energy for the electric waves. One of the transatlantic stations is equipped with a plant of over two hundred horse-power.

In the most recent Marconi transmitter, and in the Lepel and Poulsen systems, the current produced is no longer in the form of intermittent sparks, but is a true alternating current which, in general, continues uniformly as long as the key is pressed down. The result is a considerable economy in the power required for a given range of communication, and a greater possibility of accurate tuning.

CHAPTER VII

REPRODUCING SOUND AT A DISTANCE

Transmission of sound through air, water, and metals—The string telephone—The principle of the electric telephone—No sound transmitted—Telephone exchanges—Automatic exchanges—Trunk lines—The difficulty of submarine telephony—Wireless telephones.

WE are all well aware that when a body produces or emits a sound such body must be in a state of vibration in order to disturb the surrounding air and set up similar vibrations in this gaseous medium, which in turn strikes upon the drums of our ears and causes certain sensations.

We know that the air is composed entirely of gaseous particles or *molecules* of gas, which vibrate to and fro when disturbed by a vibrating body. Each little molecule has, as it were, to nudge its neighbour into motion, so it is natural that the energy thus transmitted takes time to travel to a distance, and on its way it will be gradually dissipated into other forms of energy.

Man had long recognised that air was not the only conductor of sound, and that it was indeed a very poor conductor when compared with water or metal. The speed at which sound travels through water was carefully determined by experiments made, in 1826, in the

Lake of Geneva. An ordinary bell when sounded under water could be heard at a distance of eight or nine miles by placing a large ear-trumpet in the water at the distant place. It has been suggested of late years to make use of such an arrangement for communication between ships, but the reason for referring to the matter here is merely to make it quite clear that man had definite knowledge of the propagation of sound through water. It was then quite natural to test the velocity of sound through solids, and it was determined that sound would travel fifteen times quicker through steel than it would through air. This gave rise to the scientific toy called the string telephone, and later to a practical telephone which was entirely mechanical, and consisted of a steel wire tightly stretched from one sounding disc to another. I remember seeing telephones of this class in use in public works, for communicating from one building to another. The distance over which such telephones can be used is very limited, for the energy of the sound is very quickly dissipated in moving the molecules of the steel wire.

The word telephone simply means an instrument for transmitting sound to a distance, but we now associate the word with the electrical transmission of speech. The telephone consists, like the telegraph, of two distinct parts, a transmitter and a receiver. The fundamental principle of the telephone is to control a battery current by means of sound vibrations and reproduce similar sound vibrations at a distant place. At first only musical sounds could be transmitted, and even when Sir William Thomson (Lord Kelvin) introduced Graham Bell's speaking telephone to the British Association meeting in Glasgow in 1876, it was looked upon more as a scientific toy than a thing of practical use.

In order to simplify matters I shall not describe any of the earlier telephones, but pass on to the telephone of to-day. I shall presume that the reader only desires to know how the telephone works, without learning all the details of wiring, etc. In the transmitter, or speaking part, there is a small circular disc of metal

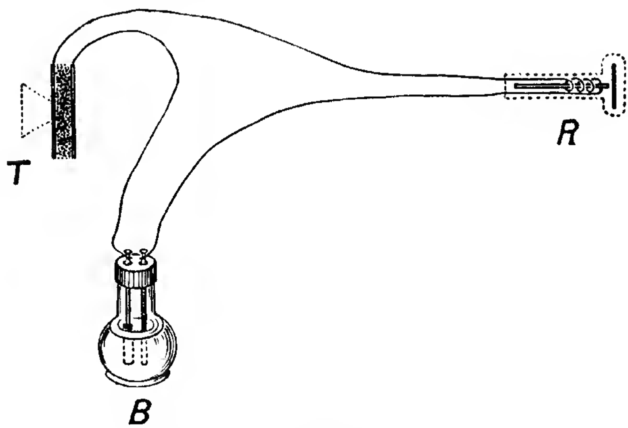


FIG. 9.—THE PRINCIPLE OF THE TELEPHONE

The current from the battery (B) passes through the powdered carbon in the transmitter (T) and goes over the line wire to the distant receiver (R). The current is controlled by the vibrations of the transmitter, and the resulting current controls the little iron disc or diaphragm in the distant receiver, as explained in the text.

about the same thickness as the leaves of this book. This metal plate, or diaphragm, will vibrate under the influence of ordinary speech, while in the receiver, or hearing part of the instrument, there is a similar metal diaphragm, which may be caused to vibrate in exact unison with the distant speaking disc. In the old string telephone the two discs vibrated in sympathy

with each other, because a tightly stretched string or wire conducted the vibrations from the one disc to the other. In the modern telephone the speaking disc controls an electric current, and the resulting current arriving at the distant receiver controls the other disc. When the speaker lifts the telephone receiver off its hook, or support, a battery current is automatically switched on to the line wire connecting his telephone to the distant one. This current on reaching the distant receiver passes round a small electro-magnet, in front of which is placed the thin sheet-iron disc. As long as a steady current flows around the electro-magnet it merely produces a steady attractive pull on the iron disc, and there is therefore no vibration. If, however, the current is made to vary, then the disc vibrates, under the varying magnetic force, and a humming sound is produced. It only remains to control these vibrations by controlling the current from the distant end of the wire. In the distant transmitter the battery current has to pass through a small box of finely granulated carbon before reaching the line wire. In passing through the carbon the current meets with considerable resistance, because of the innumerable loose contacts through which it has to make its way. If these particles of carbon are pressed more firmly together, it is natural that the current can then more easily get through from one to the other. It is therefore arranged that the speaker speaks against a thin metal disc which forms one side of the box containing the carbon, and as this disc vibrates in sympathy with the speaker's voice, it controls the battery current passing through the carbon powder. We therefore have an ever-varying electric current passing along the line wire, and when it reaches the distant station it energises the electro-

magnet in the receiver and sets up vibrations in the metal disc, which the person at that end has placed close to his ear. This little disc exactly imitates the one at the sending station; and as the sending disc is moving with the air vibrations representing speech, so the receiving disc again sets up these air vibrations which, when interpreted by the listener's sense of hearing, are recognised as speech. Undoubtedly the most remarkable thing about the telephone is that a flat metal disc can give to the air similar complex vibrations as we do with the aid of all our human speaking apparatus. There is no doubt that the accomplishments of the little imitative diaphragm fall somewhat short of the original vibrations produced by our human speaking apparatus. One has really to fill in more blanks than one imagines in a telephone conversation. This, no doubt, accounts for the difficulty some people find when using the telephone for the first time.

We now picture the diaphragm in the transmitter performing a myriad of ever-changing vibrations, while the electric current under its control is varying in a corresponding manner, and at the distant end of the line is causing the receiving disc to imitate the vibrations of the transmitter disc. It is quite evident that no sound passes along the wire, but merely an electric current controlled by sound at the one end and reproducing sound at the other end of the line.

A pair of telephone instruments permanently connected together provide communication between two definite places, but it was early recognised that if a person in one part of a city could speak to any other person in the city who had a telephone, then it would be a much greater advantage. This was easily arranged,

for it only meant bringing all the telephone wires to one central office or exchange, where any two wires might be connected together temporarily. As the telephone instruments and lines are rented annually from the Telephone Company, the parties thus hiring the telephones are called the subscribers. All the subscribers' telephone wires therefore terminate at the exchange. A very convenient way of making a temporary connection between one wire and another is to fasten a metal plug to the one wire and a metal socket on to the other wire, such as the movable plugs used in houses for connecting portable electric lamps, etc., to the electric mains. As it is necessary to be able to connect any two of the telephone wires together, it is more convenient to fix a socket to the end of every wire, and then use a short length of flexible wire, having a plug at each end. By placing one plug into the socket of one telephone wire and the other plug into the socket of another subscriber's wire, these two subscribers' telephones are then directly connected through to each other. As telephones are now arranged with a return wire instead of using an earth connection as in the telegraph, it is necessary to carry two wires from each instrument. There are therefore two wires fixed to the socket, each wire being insulated from the other. The plugs and the flexible cords are similarly arranged with two separate wires, and when the plugs are inserted in the sockets, the pair of wires are connected in such a way that there is a complete metallic circuit from the one telephone instrument to the other and back again. One wire only was at first used, the ends being earthed; but it was found that the current in one overhead wire was apt to set up or induce a similar current in a neighbouring wire, and this was more easily got rid of by making a com-

Shanghai Telephone Exchange

In the Telephone Exchange at Shanghai the operators are Chinese boys, who have proved very efficient workers. The method of making connections is easily seen.

plete metallic circuit. To simplify the description of the telephone exchange as much as possible, it is well to think only of one wire connecting the two telephones together.

The operator at the exchange may easily connect any two subscribers together, but every subscriber must be able to communicate with the operator and inform her of the number he desires to speak to. Each subscriber, of course, has a number given him, these numbers being stated in a telephone directory. If there were only a very few subscribers, say, from fifty to a hundred altogether, then one operator could attend to them all and make the necessary connections and disconnections. In some exchanges, however, there are as many as from five to ten thousand subscribers' lines to look after; it is therefore necessary to have a large number of operators. Each operator will have from eighty to a hundred subscribers to attend to, but she must be able to connect these subscribers with any other number in the whole exchange. The ends of all the wires are fastened off in small sockets arranged on a table or upright board in front of her. She can easily reach any part of this board without rising from her seat, as the sockets are made small and are very compactly arranged. This operator may therefore, by taking a flexible wire and two plugs, connect any two of these sockets together. She will, however, find her time well occupied in attending to the requests of the eighty subscribers who may communicate with her and ask her for any other subscriber in the exchange. All the sockets in the board are, of course, numbered, but when the operator receives a call from one of her eighty subscribers, whose number may be 1563, it will necessitate her locating that number before she can

get in connection with him to ask him what number he desires. It is therefore more convenient to arrange eighty other special sockets close beside the operator, and to carry a branch line from No. 1563 and her other subscribers to these sockets. These are termed the "answering jacks," the word jack or spring-jack being given to the small sockets. Each of an operator's eighty subscribers has therefore an answering jack in addition to the ordinary jack, and it will be more convenient to connect the flexible wire from one of these answering jacks to the number called for in the board. How is the operator to know when one of her subscribers desires to speak to her? There is a tiny electric lamp placed immediately under each of these answering jacks, and when the distant subscriber desires to call the operator's attention he lifts down his telephone off its support, and then depresses a push-button, which causes the tiny lamp opposite his answering jack to light up. In some cases it is arranged that the lifting of the telephone itself switches on the lamp, thus saving the subscriber the trouble of pressing the push-button. When the operator sees the lamp light up she places one end of a flexible wire into the answering jack, and by means of a small lever she can temporarily connect this wire to her own telephone instrument, the receiver of which is always to her ear. As soon as she learns the number of the subscriber wanted she switches off her own instrument and places the other end of the flexible wire into the jack or socket of the number called for. The calling subscriber is now directly connected through to his friend with whom he may converse. When he has finished his conversation and desires to have his telephone disconnected, how is he to call the operator's attention? This is very simply arranged. When she made the

connection with the calling subscriber's answering jack the signal lamp went out, but there is another lamp which represents the flexible wire. This lamp is not lighted during the conversation, not until the subscriber again depresses his push-button, whereupon this second signal lamp glows, and the operator knows that she may remove the flexible wire which was used in making the connection. It is sometimes arranged that, when the subscribers both place their telephones back upon their hooks or supports, this signal lamp is automatically switched on. This automatic arrangement is good, for otherwise it often happens that a subscriber forgets to call off when finished, so that he is believed to be engaged when he may have finished some time previously.

We now see how one operator is able to connect eighty subscribers to any other subscriber they desire; but what about the thousands of other subscribers? There is nothing for it but to have another operator for every eighty subscribers. It is clear that they cannot all sit in front of the board just described. Only three operators can work at this board without being much in each other's way, so it will be necessary to have another duplicate board for every three operators. The whole board is therefore called a multiple switchboard. Branch lines are run from each socket in the first board to similar sockets in the next board, or perhaps a better mental picture is to think of one subscriber's telephone line coming in to the exchange and passing right along through all the boards, being merely tapped at each board by a socket, just as one might have a number of water taps on one length of pipe. Each operator may now connect any of her eighty calling subscribers with any other subscriber, but here arises a difficulty. How is she to know

that no other operator has already connected some one else to the number she is asked for? Smith speaks to his operator at the first table and asks by number for Jones, and while they are speaking Brown asks his operator, who is at a different table, to connect him to Jones. What is to prevent the second operator from connecting Brown to Jones, although he is already speaking to Smith? Fortunately the operator can at once tell whether or not the line called for is already engaged. Before inserting the connecting plug she touches a small metal ring at the mouth of the jack or socket of the number called for and if she hears a loud click in her telephone she knows that the line is engaged, and she at once informs the calling subscriber of this fact. This click may be heard any day at an ordinary telephone by depressing the telephone hook or support while holding the telephone to the ear. This cuts off the battery current, and a click will be again heard when the telephone support is allowed to spring up, thus switching on the current. This click is due to the sudden making or breaking of the battery circuit. The little rings at the entrance to the sockets of one subscriber are all connected together by a wire. When the operator touches one of these rings with the wire from her own telephone no current will pass, as long as the subscriber's line is free, and there is therefore no click. If, however, any one of the jacks belonging to one subscriber is in use, the plug in it causes this wire to be connected to an earthed battery, so that if any other operator now touches one of the jacks or sockets belonging to this number she will at once hear a click in her telephone, as the battery current will get to earth through her telephone. She therefore makes no further connection, but informs the call-

ing subscriber that the number he asked for is already engaged.

It may be of interest to note, in passing, that in the United States there are several large telephone exchanges in which the services of the human operator are dispensed with entirely. The connections and disconnections are all made by inanimate automatic *selectors*, which are controlled by the subscriber himself, so that he is able to connect his own instrument with any other instrument he desires, provided the number desired is not engaged. If a number is engaged, and a subscriber endeavours to connect his instrument to it also, he hears a distinctive sound in his instrument which signifies that the desired line is engaged, and it is impossible for him to connect to this line until it is free.

One can not only speak by telephone to any part of a large city, but to other far-distant cities, and even from Great Britain to different parts of the Continent of Europe. The Londoner may converse with the Parisian although separated from each other by a long stretch of land and sea. The extent of the sea to be spanned is the main factor in determining the possible distance to which one may speak. As long as telephones are connected by bare overhead wires, conversation may be quite conveniently carried on over a distance of a thousand miles and more, but when it is necessary to enclose the wire in an insulated cable, whether placed under the ground or sea or not, it is quite a different matter. The greatest expanse of sea that has been successfully spanned so far will not exceed fifty miles. A simple relay or repeater such as is used with telegraph instruments is of no use for a telephone. The telegraph current is a make and break arrangement, whereas the

telephone current is a much more delicate and ever-varying or undulatory current. Can nothing be done to intensify the telephone current? Every telephone current is intensified before it leaves the transmitter, by passing through an induction coil, the principle of which will be explained in the following chapter. It is not very convenient, however, to introduce induction coils inside a submarine cable. Some interesting experiments have been made by the electricians of the British Post Office with a long stretch of cable on land. A cable which could only carry speech a distance of sixty-six miles was so improved by the introduction of an induction coil at every mile, that when thus arranged it was possible to converse through one hundred and seventy-six miles of the same cable. We still await some practical method whereby a cable may be made to carry telephone currents across the Atlantic.

It is not easy to grasp the full meaning of this difficulty in transmitting a telephone current through a long insulated cable. This difficulty has already been referred to, but the trouble is increased when instead of the telegraph current we substitute the delicate telephone current. The trouble is due to the fact that when an electric current passes along a cable there is not only the effect produced in the conductor, but also in the neighbourhood surrounding the wire. We may picture the current in the wire setting up or inducing another current or electric charge in the sheathing of the cable or in the surrounding surface of the sea-water itself. This induced charge attracts the current being sent along the wire and thus retards it, so that it is partly dissipated and arrives in a very much weakened condition. Perhaps a more correct mental picture, though not so picturesque, is to think of the moving

current setting up an electro-magnetic disturbance in the ether around the cable, and it is clear that in so doing it must expend some of its initial energy. This troublesome property of a cable is due to its capacity, and while this may be balanced to a certain extent for a telegraph current by adding condensers at either end of the cable, this will not avail in connection with delicate telephone currents operating sensitive instruments. When a submarine telegraph cable is connected to condensers the cable is not directly earthed. It is just as though the cable was connected to a metal plate at each end and left insulated from the earth, but another plate is placed very near to the first plate, and this second plate is connected to earth. With an arrangement of this kind it is found that the signals are very much improved, so that as far as telegraphy is concerned the difficulty has been overcome and the signals kept quite clear of each other. It is only reasonable to suppose, however, that the telephone current which we may picture as a gentle ripple of waves, in contradistinction to the telegraph splash, is more easily affected by the retarding effect, so that the controlling current becomes distorted and quickly dissipated.

The long-distance telephone lines connecting distant towns together are called trunk lines, and the transmitting power of these is so good that sometimes when one is conversing with a man distant many hundreds of miles, it is difficult to realise that he is not really quite close at hand.

I remember on one occasion after travelling by the 2 p.m. express train from Glasgow to London, I desired to communicate with my home, which is in a country district distant more than four hundred miles from London. On reaching my hotel about 11 p.m., I gave

the required number to the telephone operator, and in less than two minutes I was speaking through to my home. Of course, in the daytime during business hours one has to wait one's turn as the number of trunk lines is limited.

CHAPTER VIII

WIRELESS TELEPHONY

First wireless telephone—Speaking along a beam of light—Induction method with parallel circuits—Practical installations—Attempts to telephone with the spark-telegraphy system—Dispensing with the spark-gap—Transmitters with an electric arc—A modern system—The distance already spanned—Interference or cross-talk difficulties—Professor Ayrton's early prophecy.

IT is of interest to note that a wireless telephone existed long before any wireless telegraph experiments were made. Very shortly after the invention of the telephone it was discovered that speech might be transmitted along a beam of light. The disc or diaphragm of the transmitter was a thin plate of silvered glass or mica, forming a flexible mirror. A powerful beam of light, electric or sunlight, was thrown upon this little mirror, and from there it was reflected to a distance, first of all passing through a lens which focused the light into a beam of parallel rays. This beam of light fell upon the distant receiving apparatus, in which was placed a selenium cell. Selenium has a well-known and peculiar property; its resistance to the passage of an electric current through it varies according to the amount of light falling upon it. The more light, the more current passes. Hence when the little flexible mirror diaphragm is made to vibrate by the speaker's voice it alters the light falling upon the distant selenium receiver, and this controls a battery current passing through a telephone receiver. In this way the

movements of the transmitting disc, the mirror, are imitated by the disc in the telephone receiver, and the speech is reproduced. This is true wireless telephony, and has been employed in speaking from shore to ferry-boats in the United States, but it is quite apparent that the possible distance of transmission is very limited.

Another obvious method of wireless telephony is by induction. When using the ordinary telephone a subscriber sometimes complains to the exchange operator that some other line has "got mixed up" with his, as he can hear conversation between other two parties. When the operator informs him that it is merely *cross-talk* which he hears he is probably somewhat mystified, and in any case he is annoyed by the continuance of this cross-talk conversation. Of course, what is occurring is beyond the control of the operator; it is the result of the varying current in one party's current inducing a similar current in another party's circuit.

A practical system of wireless telephony has been adopted upon this plan, which is really the same as Sir William Preece's wireless telegraph system with a telephone transmitter in the sending circuit. Preece made use of this wireless telephone system to establish communication between the lighthouse on an island (the Skerries) off the coast of Anglesey. At this point on the coast the sea bottom is exceedingly rough, and the tidal currents are so great that it was useless to attempt to lay a submarine cable.

The distance between the island and the mainland is about two and three-quarter miles, and it was found that when a comparatively short wire, of less than half a mile, was run along the island, and a parallel wire of about three and a half miles in length was erected on the mainland, a good inductive effect was obtained between

these two distant circuits. The people on the island could converse with those on the mainland, although nearly three miles distant from one another. The fact of being able to use a telephone instead of a telegraph, with its accompanying code, was a distinct advantage. This installation is still in use, as also is a similar installation for transmitting wireless signals between the Rathlin Isle and the Irish coast. The distance spanned in this case is nearly eight miles, while the line on the island is rather more than one mile in length, and that on the mainland about five and a half miles. It is obvious, however, that the distance over which this parallel wire system may be used conveniently is very limited.

Experimenters naturally turned their attention to the spark-telegraphy systems, which have been described in chapter VI. In some experiments an arc lamp was used as the variable transmitter, but while it was found possible to transmit musical tones, all attempts at reproducing speech gave very poor results. Many similar plans, to control a spark discharge by sound, have been tried, and with more rapid sparking arrangements much better results have been obtained. Recent advance, however, has been made in dispensing with a spark gap, and causing the sound merely to vary a continuous emission of ether waves, produced by rapid electric oscillations in an aerial wire.

One system, based on the foregoing principle, was devised by Professor Fessenden of the United States. In this a microphone transmitter was placed in the path of the surging current which sets up the ether waves, so that as the microphone varies the wave-producing current varies in sympathy with it. As early as 1905 the *National Electric Signalling Company* (U.S.A.), working Fessenden patents, undertook to equip wireless

telephone installations "guaranteed up to distances of 25, 50, and 100 miles."

We have seen already that the electric arc was used as a transmitter in the attempts at spark telephony, but without success. When the electric arc, however, was introduced as a producer of continuous waves great progress was made and practical wireless telephony was established.

We need not trouble with many details, but a general idea of a modern installation of wireless telephony will be of interest. A special arc is used, and this is surrounded with ordinary coal gas in place of air, while means are adopted to keep the arc well defined and constant. This is enclosed in a box with a cooling apparatus. If several arcs are used in series the power of transmission is increased. The microphone transmitter is placed in a battery circuit, and the variations in this circuit induce changes in a neighbouring circuit in which is placed the arc which acts as a generator of alternating current of very high frequency. This electric current, varying in sympathy with the sound vibrations in the first circuit, induces electric oscillations in an aerial wire, which has one end earthed and the other extending upwards into the atmosphere. These electric oscillations in the aerial wire disturb the surrounding ether of space, and send out electric waves. Those electric waves arriving at the distant station are absorbed by the receiving aerial wire and affect a suitable detector (an electrolytic cell), and control a local battery current which operates an ordinary telephone receiver, in which the original sound is reproduced.

It is now possible to speak over a distance of nearly two hundred miles by wireless telephony, and it is of interest to note that the United States Navy, after an

exhaustive trial, have ordered twenty-eight sets of wireless telephones capable of speaking over distances up to twenty-five miles. It is obvious that the greater the distance required to be spanned the more powerful does the generator require to be.

It is apparent that wireless telephones will be subject to cross-talk, but this difficulty is being fought by the adoption of "tuning," of which we have seen the general principle in chapter VI.

Who knows but Professor Ayrton's humorous prophecy may be fulfilled at some future time? In the first days of wireless communication the learned professor spoke of a time when, "if a person wanted to call to a friend, he knew not where, he would call in a loud electro-magnetic voice, heard by him who had the electro-magnetic ear, silent to him who had it not. 'Where are you?' he would say. A small reply would come, 'I am at the bottom of a coal mine,' or 'crossing the Andes,' or 'in the middle of the Pacific.' Or perhaps, in spite of the calling, no reply would come, and the person would then know his friend was dead!"

CHAPTER IX

HOW INDUCTION COILS WORK

The meaning of "induction"—An early telephone trouble—Sir William Preece's system of wireless telegraphy—Self-induction—The general principle of the induction coil—What we gain—Make and break arrangements—An analogy—The construction of an induction coil—The use of the condenser—A simple analogy—Why the resulting current is not an alternating one—Uses of induction coils.

IN our every-day life we are quite at home with the verb *to induce;* we do not require to consult a dictionary to learn its meaning. When we are informed that a man has been *induced* to go to a certain town, say for some public purpose, we do not picture the man being taken there by force. We may think of him having some difficulty in acceding to the request, but when outside influence is brought to bear upon him he is *induced* to go.

We have a somewhat analogous idea when we speak of one body inducing electricity in another body. If it be an electrically charged body we mean that its very presence will induce a complementary charge upon a neighbouring body. If we are speaking of a wire circuit with an intermittent electric current flowing in it, we may say that the current *induces* a complementary electric current in a neighbouring and parallel circuit.

It is natural that we should use the word *induction* to distinguish such results from mere *conduction.* In the latter case we conduct the electric current from one

body, by means of a conductor, to a second body, whereas in the former case we *induce* an electric current in a circuit with which we have no material connection. That there must be a medium for all communications goes without saying, and in the case of electric induction the medium is the all-pervading ether.

Sometimes induction takes place accidentally between two circuits. In the early days of the public telephone service, the telephone engineers were troubled very much with induction difficulties. On one occasion some subscribers in London complained of clicking sounds in their telephones, and these noises became very annoying during a conversation. It was found that these subscribers' lines passed along a certain street under which some telegraph cables were laid, and there could be no mistaking the cause of the annoying clicks; they were, undoubtedly, the Morse telegraph signals. The telephone wires were on poles on the top of high buildings, while the telegraph wires were in cables buried in the earth, and yet the intermittent current in the one wire induced a similar current in the other distant wire.

When dealing with the subject of wireless telegraphy I made no mention of Sir William Preece's system, although it was the first in the field, because it is based upon a different principle from the systems now in use, but a brief description of it may be of interest at this point.

Preece's wireless telegraph system is dependent upon this phenomenon of induction which we are considering. Just as the Morse signals were transferred accidentally to another parallel circuit in the case stated, so Preece endeavoured to send such signals over a much greater distance. The sender had a long straight wire, which, unfortunately, had to be about as long as the distance

over which the signals were to be transmitted. The sender had a convenient means of making and breaking the flow of an electric current in this long line, which, of course, was earthed at both ends. The distant receiver had a similar long parallel wire, and in circuit with it he had an ordinary telephone receiver. When the sender set up a momentary current in his long sending wire, the operator at the receiving end heard a distinct click in his telephone, and by such means it was found possible to signal the Morse code over a considerable distance without connecting wires. But from the amount of wire required one can hardly call this a wireless system. It is obvious that if we must increase the length of the two distant wires, with the increasing distance separating them, there is nothing to be gained unless in very exceptional circumstances, such as in signalling across a gulf without laying a submarine cable.

Some one might suggest that the long parallel wires should be rolled up in the form of coils, and placed parallel to one another. This, however, would alter the condition of things entirely. The disturbed ether would react upon the current in the sending coil and the transmitting energy would be baffled. This condition of things is known as *self-induction.* Before we can have action between the coils they must be close to one another. We have a practical application of such an arrangement in the induction coil.

In these days of X-ray work, almost every one has some acquaintance with an induction coil. Probably some of us have youthful recollections of electric shocks dealt out by small toy induction coils.

The general principle of the induction coil will be seen in the following diagram, Fig. 10.

By an induction coil we mean a machine by which a

current of electricity in one wire or coil will induce a similar current in a second and separate coil. One may naturally ask what advantage is to be derived by doing this. The result of a preliminary experiment seems rather disheartening. We fit up two coils, connecting one to a battery, and we place the second coil near it, this coil being attached to an instrument for detecting the flow of a current. The diagram (Fig. 10) shows this

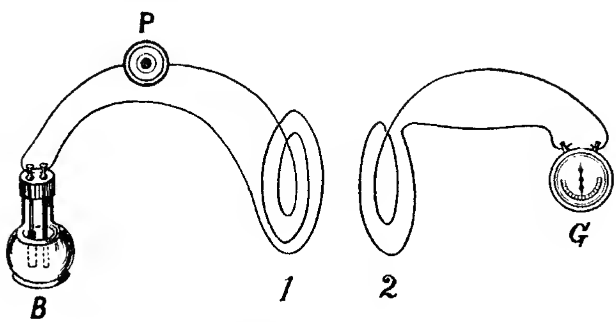


FIG. 10.—THE PRINCIPLE OF INDUCTION COILS

When the push (P) is pressed a current flows through coil No. 1 from the battery (B), and at the making and breaking of this current an electric current is set up in coil No. 2, which is quite separate. This induced current is detected by the galvanometer (G).

simple arrangement with a bell-push inserted between the battery and No. 1 coil, so that we may conveniently switch off and on the current at will.

We know that as soon as we press the push a current will flow in No. 1 coil. We press the button, and watching the detecting instrument in the other coil, we see its indicator fall to one side, showing that a current of electricity has been set up in No. 2 coil, and it is clear that this current must have been produced by induction

from the battery current in No. 1 coil, as there is no connection between the two coils. Still keeping a finger on the push, we notice that the indicator has gone back to zero, showing that the current is no longer flowing in No. 2 coil, although the battery current is still flowing in No. 1. When we let go the push, we notice the indicator in No. 2 coil move once more, but this time in the opposite direction, and by repeating the experiment we find that every time we make or break the battery current in No. 1 coil a momentary current is set up in No. 2 coil.

We may leave the current produced at make out of account altogether, for reasons which will be explained later. We need only remember that each time we press and let go the push in No. 1 coil a momentary current is set up in No. 2 coil. The quicker we press the push the more of these transient currents do we set up, and if we could make them follow very closely at each other's heels, they would make practically a continuous current.*

We cannot hope to operate a bell-push rapidly enough to get this effect, and so automatic contact breakers are required. The induction coil may be made to do this itself, or it may be mechanically done by a small motor, but first of all we wish to see what advantage an induction coil is going to give us.

We may imagine No. 1 coil sending out electro-magnetic waves in the ether, and these waves, as they fall on coil No. 2, setting up a current in this coil. It is the changes in this field of influence which give rise to the induced current, for as long as the battery current keeps up a steady influence, no current is induced in No. 2 coil, but only when the waves are being set up or with-

* If the momentary currents follow each other at the rate of twenty per second the result would be a practically continuous current, so all we have to do is to find a means of breaking the battery circuit twenty times per second.

drawn does the current appear in the neighbouring coil. The more of these waves or lines of force we can entrap the better result we get, and we find the effect increased for every turn of wire we add to No. 2 coil, so we make this coil of very fine wire in order to get a great many turns into the field of influence. If we made the two coils exactly alike we should gain nothing, and even now we cannot hope to increase the amount of electricity, but we may alter its condition. We may think of the battery current in No. 1 coil as an easy-flowing current of considerable volume, while in No. 2 coil we have a small current at a very great pressure. It is difficult to find any convenient analogy, but I think one may liken the process to that of a mechanical lever. A workman wishes to move a large stone, but finds it too heavy. He gets a simple bar of iron, and putting one end under the stone, he places some obstacle under the bar or lever near to the large stone, and then applying his energy to the free end of the lever, he finds he can easily move the heavy stone. From whence did he get the increase of power? Energy cannot be created by a simple iron bar or by any other means, but it is apparent that the workman moved the free end of the lever through a far greater distance than the stone was moved, so that he merely concentrated his energy. We might speak of the energy he put into several feet of movement being concentrated into several inches, and this may serve as a rough analogy of what an induction coil does: it cannot increase the energy, but it concentrates it, and we have a very high voltage or pressure, sometimes reaching over a million volts. A single battery cell gives a pressure of from one to two volts.

When the principle of an induction coil is once grasped, the construction is readily understood. No. 1 coil, which

is the battery circuit, is called the primary coil or circuit, while the coil in which the current is to be induced is called the secondary circuit. The electro-magnetic effect of the primary coil is increased enormously, by placing a piece of iron inside the coil. A bundle of iron wires is used, as they magnetise and demagnetise quicker than a solid piece of iron does. The battery or primary circuit is wound around this bundle of wires, the coil being, of course, carefully insulated, or otherwise the current will not go round and round the coil as is desired. One may always think of the insulation being to the current what a pipe is to water or gas. The two ends of this primary coil are connected to the battery, there being a contact breaker inserted between one end and the battery, as was represented in the diagram (Fig. 10) by the bell-push. The secondary coil of very fine wire is wound directly on the top of the primary coil, but very carefully insulated from it, and its two ends are left free, being merely finished off in convenient terminals, so that any desired piece of apparatus may be connected in circuit with this coil.

As already indicated, the contact breaker may be worked by the induction coil itself, for the bundle of iron wires, becoming a magnet whenever the battery current flows round them, may be made to attract a piece of iron attached to a spring, which, when attracted forward, breaks the path of the current from the battery.

Immediately the circuit is broken the bundle of iron wires lets go the spring piece, which, coming once more to its normal position, allows the current again to pass, whereupon the spring is again attracted forward, and so the make and break is kept up continuously. The motion is exactly that of the gong-stick in an ordinary electric bell, and it is the rapid to-and-fro movement of this

spring that causes the monotonous hum in the air when an induction coil is at work.

The breaking of the battery circuit might be accomplished by turning a wheel round, having contact pieces at intervals on its periphery, and indeed this method was employed prior to the automatic arrangement just described. One modern method is to give a rapid motion to a contact lever by means of a small motor driven by electricity. There are also electrolytic contact breakers now in use, but the object of all is merely to obtain a rapid make and break of the battery circuit. The only other point to mention is that a condenser, made up of insulated layers of metal foil, is placed in the wooden base of the instrument, to act as a Leyden jar. The induction coil is also supplied with a switch, to turn off and on the battery current at will, and also a commutator switch, so that the direction of the current may be reversed.

It may be interesting to add a few words of explanation in connection with *condensers*. It is difficult to find any really helpful analogy, for if we picture a condenser merely as a reservoir the analogy is very incomplete. If we imagine the charged condenser as analogous to a tightened steel spring, we get some rough representation, when the spring is released suddenly, of the electric oscillations occurring during the discharge of a condenser. But perhaps the following analogy will be more helpful for our present purpose.

Suppose we take a pressure air pump to represent an electric battery, and a very elastic bag to represent a complete condenser with its two sets of plates. We then have a tube connecting those two, and this will serve to represent the electric circuit, while a stop-cock in the connecting tube will stand for a make-and-break

arrangement in the electric circuit. As soon as the stop-cock is opened the pump forces a gas along the connecting tube into the elastic bag, which quickly fills and becomes distended. If the pumping pressure is very great the walls of the gas bag may burst, or if that somewhat exceptional calamity does not occur, there may be a leakage of gas through the walls of the bag. This leakage is sure to occur in all cases unless the walls of the bag are sufficiently thick. We close the stop-cock, the pump stops, and leaves the gas-bag distended, charged with gas. If we now open the stop-cock suddenly, the pump commences to work once more, but the back-rush of gas from the distended bag retards the action of the pump. In our analogy it is the space inside the bag which represents the sheets of metal foil in the condenser, while the walls of the bag represent the insulating material or *dielectric*. It is the dielectric which is ruptured in the case of overcharging with no possible way of escape for the charge.

Our analogy is necessarily incomplete, for the sheets of metal foil do not act merely as simple capacities, but assist one another in this wise. When an earthed metal plate is brought into the neighbourhood of another plate which is being charged, the capacity of the plate is enormously increased. In the induction coil we do not earth the plate, or set of metal foils, we simply connect the condenser as a shunt circuit from the battery. When the current is switched on to the induction coil, the condenser is charged immediately, and at the same moment the main circuit is broken by the forward movement of the spring-piece or *hammer*. When the hammer springs back and closes the battery circuit once more, the condenser discharges into the main circuit and the back-rush of current retards the starting of the battery

current. The result of this is that the current does not start suddenly enough to cause an appreciable inductive effect in the secondary circuit, in which there is an air gap, while the rapidity of change at the break is very much greater. Hence we have practically a unidirectional or direct current issuing from the terminals of the induction coil, and not an alternating current as one might suppose.

The use of condensers in connection with military field telephones will be explained in the last chapter, when we shall be dealing with the electron theory.

Induction coils have been of great service in connection with telephones, an induction coil being an absolute necessity unless for telephones used only over a very short distance. Then we find large induction coils playing a most important part in the production of Röntgen rays, while a great deal of the experimental work carried out in connection with the electron theory has been dependent also upon the use of large induction coils.

CHAPTER X

CONCERNING LIGHTNING

Its nature—Franklin's experiment—An experimenter receives a fatal shock—Lightning conductors—Protecting electric circuits against lightning—Fork lightning—Sheet lightning—Ball lightning—Bead lightning—Thunder—The immense electric pressure in lightning.

WHILE primitive man was mystified and terrorised by great flashes of lightning descending upon the earth, civilised man has been able to discover the nature and cause of this gigantic phenomenon.

When the illustrious American philosopher, Benjamin Franklin, suggested that lightning was merely an immense electric spark, it seemed too bold an assertion. But he, and others, were soon able to prove that lightning was an electrical discharge from thunderclouds. By sending up a kite into the neighbourhood of thunderclouds, Franklin was able to "draw the lightning from the clouds." The wetted string of the kite was used at first as the conductor, but this was improved upon by another experimenter, who twisted a metallic wire with the string of the kite, thus offering the electric charge an easier way of escape from the kite to the earth-end of the string. Holding the wire by a silken cord, which acted as an insulator, this experimenter made many interesting electrical experiments. It must be clearly understood that these experimenters did not intend that their kites should act as lightning conductors, but merely

as a means of tapping the thunderclouds, and conducting away some of the accumulated electricity. The man who used the metal wire was able to conduct away more electricity than the man who used the wetted string of the kite.

It is obvious that there was a certain amount of danger in playing with atmospheric electricity, although the experimenters had no idea of inviting the lightning on to their strings or wires; they intended only to tap the electrified cloud and draw off some of the charge. One Russian professor, however, when making some similar experiments in St. Petersburg, received a fatal shock during a thunderstorm. This unfortunate experimenter, Professor Richmann, had arranged a vertical rod from the roof of his laboratory, and connected this to a metal ball on the ceiling of the room; but he had omitted to provide any possible way of escape for the electricity to earth, and on coming near to the metal ball his body formed a conductor, so that the lightning discharged through his person.

It became clear that if a pointed conductor was placed on any high erection, such as a church steeple, and if the lower end of the conductor was connected to the earth, then the lightning could be conducted safely to the earth without any damage being done to the building. The electricity would not trouble to go through the stone building when such an easy path was offered it by the metal conductor.

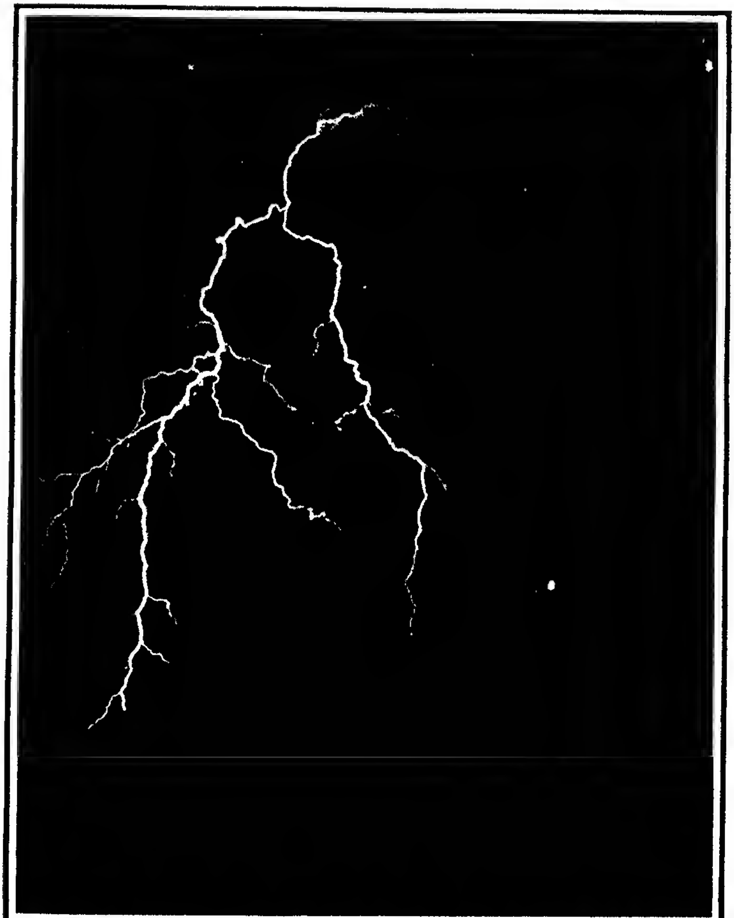
In constructing lightning conductors it is advisable to give the high-tension discharge a clear path and a good connection with the earth by means of a large metal plate sunk in the sub-soil. The water mains may also be connected, but if we fail to give the electricity a clear path, it may leave the conductor and do much

damage to the property which we are seeking to protect. It has been pointed out that the only sure lightning-conductor is to cover the building with a wire gauze. It is not convenient to put an ordinary building into a metallic cage, but it is wise to adopt such precautions in the case of powder magazines or stores of highly inflammable materials.

Other forms of lightning protectors have been devised to safeguard electric circuits that are exposed to the elements. In these circuits an earth wire is provided, which, of course, is not connected directly to the electric circuit, else the line current would take a short cut to earth by it. It is sufficient, however, to have the end of the earthed wire placed in close proximity to the conducting wire, leaving only a small air-gap between. It is quite impossible for the line current to leap across this air-space resistance, but if lightning strikes the conducting wire it can laugh at such trifling obstacles, and, by its great pressure, leaping the air-space it gets safely to earth without damaging any of the electrical instruments in the exposed circuit.

A simple fixed air-gap is quite sufficient in connection with telegraph and telephone circuits, where only a very small electric pressure is used. In the case of expensive submarine telegraph cables great care must be taken in providing an efficient lightning protector for the land wire, for if lightning were to strike this wire and reach the submarine cable it might rip up the insulating cover and leave the cable useless.

Lightning does not often appear as a simple long spark or streak of light, but branches off in different directions from the main line, and all such discharges we commonly call zig-zag or fork lightning. What we know as summer or sheet lightning may be merely the reflection



By permission of] [*Mr. Taylor, Paisley Museum*

FORK LIGHTNING

The lightning discharge is exactly similar to the spark from an electrical machine, but on an immensely grander scale. The discharge is between a cloud and the earth.

of one of these fork discharges occurring behind a cloud, or it may be that sometimes there is a diffused or partial discharge in the interior parts of the same cloud.

There is another class of lightning called globular or ball lightning; but this is much rarer, and is distinguished by its slow diffusion, its duration far exceeding that of ordinary lightning. There is no doubt that such forms of lightning are visible for at least ten seconds, and there are reports of much longer durations. The damage done by this form of lightning is often very great, so that an erroneous idea got about that on such occasions there was a material thunderbolt lodged in the earth, this notion being the result of reports describing the holes actually made in the ground where the ball lightning fell. The ball of fire is undoubtedly material, but it cannot very well be composed of anything but air and gases derived from water-vapour, the whole mass being in a highly electrified state.

There has been observed on rare occasions a "bead" form of lightning, in which the long flash appeared to be made up of little globes of fire forming a train. This bead lightning would seem to be an intermediate between fork and ball lightning.

When a long electric spark is drawn from a very large electrical machine, there is a considerable noise produced, like the report of a gun, and the same occurring on a much grander scale in the heavens, where the noise is echoed from one cloud to another, produces in our ears the effect of the thunder crash. The electric disturbance sets up air vibrations or sound waves. These travel through the air at a very slow speed, about 1100 feet per second, so that it takes the thunder some time to reach us. Light, however, travels through the ether at an immense speed, not falling much short of 200,000

miles per second. The light from the lightning therefore reaches us much quicker than the sound of the thunder. In this way we have a very simple method of calculating how far distant the lightning is from us. If we only desire an approximate figure, we may reckon the sound travelling at a speed of one mile in five seconds. If we count the seconds after seeing the flash, and find that there is a silence of fifteen seconds before the thunder is heard, then we know that the thunder has travelled a distance of three miles.

If after seeing a flash of lightning we fail to hear any thunder, it may be that the flash we saw was merely a reflection of some far distant discharge, or it may be that the lightning we witnessed was at a greater distance than fifteen miles from where we were, for that is about the limit of the carrying power of thunder. We therefore see that there cannot be a great deal of energy in the thunder crash, for the report of a cannon will carry nearly four times this distance, while the noise of a bombardment will travel twice as far again. There is, however, an immense electric pressure in the lightning discharge, so much so that we often witness most alarming destruction of property and life. If we consider the electric pressure required to produce quite a tiny spark across an air space we shall then appreciate the energy in a lightning discharge. Remembering that a single chemical cell or "battery" only gives a pressure varying between one and two volts, we may be somewhat surprised to learn that a pressure of one thousand volts is required to cause electricity to jump across a tiny air-gap of the one-hundredth part of an inch. If the ends of two wires are touching each other when the current is started and they are then separated, the conditions are quite different, as a bridge is formed of gaseous particles

torn off from the ends of the wires. At present we are considering two points with an air space between them at the outset. It is indeed remarkable that this small air space offers so great a resistance. If we now think of a lightning flash sparking across a distance of one mile, we may form some idea of the enormous electric pressure required.

CHAPTER XI

THE MEANING OF THE ELECTRICAL UNITS

Ordinary measures of material things—The need for exact electrical measurements—Absolute units—The practical unit of electric pressure—The unit of current strength—The unit of electrical resistance—The relationship of these units—Other units—How the pressure and current are measured—Electric meters.

SOMETIMES we say that one object is three times as large as another or only half the size of another, and although we have more exact methods, all our measurements of material things are merely comparative. The rulers of the land laid down certain artificial standards with which we should compare the length and weight of all objects. These standards are retained under lock and key in London.

A bronze bar thirty-eight inches long has two gold studs sunk into the bar near its ends, on both studs a line is cut, and the distance between these two parallel marks is the length which they have determined as the unit *one yard*, but in order to be exact the measurement must be made when the metal bar is at a temperature of 62 degrees Fahrenheit. All other lineal measures are either smaller parts or multiples of this definite but artificial standard. The unit of weight is similarly defined by a certain piece of platinum preserved in the Standards Office. Four copies of these standards are deposited in other places of safety, in case of accident,

while we all possess some more or less faithful imitation of these measures for our personal use.

The case is somewhat different with electricity. We construct standard electrical instruments which we use in practice, but these have not been based on any such artificial plan as adopted for length and weight. The units of electrical measurements have been scientifically determined, and can be reproduced at will; so that, while all our measuring of electricity in practice is done by comparing the effects produced on standard instruments, we do not require that our legislators should lock up any of these instruments for a standard reference. The scientist could reproduce them again at any time if required. This question of scientifically-determined units will become clearer as we proceed.

When the first Atlantic cables were laid, we had no standard electrical measurements. Electricians had made measuring instruments, but there were no definite units by which the effects might be reckoned. In the same way our early thermometers had no fixed scale. This want of any electrical units was found very awkward. There was no use of one electrician reporting to another that the current required to be used "is such that it moves the indicator of my measuring instrument forty degrees." This value would depend altogether on the construction of the said instrument, and the particular way in which the scale of degrees had been divided. It was quite evident that if we were to make practical progress we should require some system of standard units of measurement. We might have gone upon the artificial plan of simply taking any one particular measuring instrument, and agreed that when the indicator of this instrument moved a certain distance, we should reckon that particular value as the unit.

Our legislators would then have taken charge of this instrument and allowed us to make duplicates, which could be standardised from the original instrument. A wiser plan was adopted.

The British Association, in 1861, appointed a committee of the foremost scientific men of the day, with Sir William Thomson (Lord Kelvin) as president, and the object of the committee was to suggest a suitable basis of electrical measurement. Many years elapsed before the final results were made public, but units of electrical measurement were determined upon purely scientific principles. These units were called the absolute units, the word absolute meaning that they were free from any particular conditions, or, in other words, that they had reference to no artificial electrical standard, but could be scientifically reproduced at any time.

We shall be content to know that these scientists arranged for us certain definite units of electrical measurement.

It so happened that the units thus scientifically determined were not of convenient size for measuring the currents we have to deal with in practice, and the committee therefore arranged a series of practical units, which are definite multiples or sub-multiples of the absolute units. By the word *sub-multiple* we mean a number which is contained in another a certain number of times.

We are quite familiar with the idea of pressure in connection with flowing water, and we state this as being so many pounds to the square inch. When we have electricity flowing along a wire we may measure the electrical pressure, but we cannot state this in any ordinary measures, and so we coin a word to represent a unit of electric pressure. The committee of the British

Association named it after the illustrious Italian, Professor Volta, who discovered the means of producing an electric current by chemical process. The *volt* is a definite multiple of the absolute unit of pressure, which was scientifically determined, but the reader may form an idea of its value from the fact that the electric pressure at which any primary cell delivers its current is always between one and one and a half volts.

Before leaving the subject of voltages, it will be well to fix in one's mind the fact that the number of volts does not signify the quantity of electricity passing along a line, but merely indicates the pressure at which the current is being delivered.

In order to measure the working value of water flowing in a pipe we must know more than the pressure at which it is being delivered. We require to know its rate of flow, which we say is so many gallons per minute. We must have an equivalent measurement in electricity. As some new word had to be coined to express the unit of current strength or rate of flow, it was a happy suggestion to immortalise the name of the great French scientist, Professor Ampère. When we use the word ampere to denote this electrical unit, we find it more convenient to omit the accent as used in the proper name. If one remembers that the ampere in electrical measurements is used in a similar sense to the words "one gallon per minute," there should be no confusion. We may say that it requires a current of one quarter ampere to make a certain glow lamp light up, or that we must have a current of ten amperes for a certain arc lamp. These statements merely imply the current strength or rate of flow of the current. They are not measures of quantity.

How are these two units, the volt and the ampere, related to each other? It will be of service to return to

the analogy of water flowing through a pipe. If the water is being delivered at a low pressure we must have a considerable rate of flow, or in other words a large volume of water, to do any work, and we consequently require pipes of a large diameter to conduct the water. The electrical side of the analogy will be clear as we go along. If we increase the pressure of the water we may use less water and consequently smaller pipes. A flow of a very few gallons per minute, in a small pipe, at a high pressure, may drive a water turbine, and do the same work as hundreds of gallons per minute passing over a water-wheel at a low pressure. It is therefore apparent that the power of doing work is dependent upon both the pressure and the rate of flow. If we increase the pressure then we may reduce the rate of flow, or the other way about.

The electrical resistance of any conductor is, of course, increased by adding to the length of the conductor, and also by reducing its cross section or diameter. There seems little room for confusion here, and yet I have found beginners thinking that the large conductor should offer greater resistance than the smaller one. No doubt it is the solidity of the conductors that leads them astray. A piece of solid metal two feet square will offer a far greater mechanical resistance than a piece two inches square. The matter should be clear, however, if one keeps in mind the analogy of the water pipe. A pipe of small bore offers a greater resistance than one of larger bore. The analogy is by no means a perfect one, for in considering the resistance of a pipe to a flow of water in it we have to take into account the pressure of the water current, whereas the electrical resistance of a wire is constant no matter what voltage is used. Electrical resistance is an inherent quality of a conductor.

It is true it may increase or decrease with a fall or rise of temperature, but it is not affected by the pressure of the electric current.

We must have a unit by which we can measure the electrical resistance of a conductor. The unit has been very conveniently arranged, for it is the resistance which requires a pressure of one volt to drive a current of one ampere through it. This unit has been called the ohm, after Professor Ohm (Germany), who first pointed out that the strength of an electric current not only depends upon its pressure but also upon the amount of resistance offered by the conductor in which it is flowing. This, when stated mathematically, is known as Ohm's law. The standard ohm is the resistance offered by a column of mercury 106·3 centimetres long and one square millimetre in cross section, at a temperature of 0° Centigrade.

Perhaps it will be easier to form a clearer idea of the value of an ohm by taking an example employing measurements with which one is more accustomed to deal. Roughly about six hundred yards of copper wire one-tenth of an inch in diameter offers an electrical resistance of one ohm. Three hundred yards of the same wire will have a resistance of half an ohm, while sixty yards will only offer a resistance of one-tenth of an ohm.

It will be of service to remember that the units are so arranged that it requires a pressure of one volt to send a current of one ampere through a resistance of one ohm. It will therefore require a pressure of two volts to send the same current through a resistance of two ohms. A pressure of one volt would, however, send a current of half an ampere through a resistance of two ohms, and so on.

It may be of interest to remark in passing that the

potential is not the same throughout the whole length of the conductor. The pressure or potential falls from point to point. If the circuit is of uniform resistance throughout, there will be a regular fall of potential along its length. The current strength or rate of flow (amperes) will, however, be the same in all parts of the conductor, even although the circuit be made up of lengths of wire of various diameters. The electrical energy, which as already pointed out is the product of the pressure and the rate of flow, must necessarily fall with the decrease of pressure. We therefore speak of electrical energy being consumed although we understand that it is merely transformed into some other form of energy. The electrical energy lost owing to resistance in the conductor is transformed into heat energy. If the conductor be a large one this heating effect will not be perceptible.

When one is informed that the ampere is analogous to the measure "one gallon per minute," it is natural to wonder why both quantity and time are not mentioned in this electrical unit by which the rate of flow is measured. The word ampere in order to signify a rate of flow must necessarily mean a certain quantity in a certain time. We seldom meet the unit of electrical quantity outside of the scientific laboratory, but it has been named the coulomb after a great French physicist, who lived a century ago. This practical unit of quantity was fixed by the British Association committee at one-tenth of the absolute unit of quantity which they had scientifically determined. It may give the reader some idea of what a coulomb is, to say that if that quantity of electricity is passed through an electro-plating apparatus it will deposit rather more than one milligramme of silver. That is the meaning of a coulomb, and the

ampere is a rate of flow of one coulomb per second. With this fuller statement of the meaning of an ampere, the analogy of one gallon per minute becomes more obvious.

There are other electrical units with which the scientist deals, such as the unit of electrical capacity, which has been named the farad, after our illustrious Michael Faraday who made so many important discoveries while at the Royal Institution in London.

What about the measuring of volts and amperes? We have a voltmeter for indicating the electric pressure in volts, and an ammeter (ampere meter) for indicating the rate of flow of the current in amperes. These are not really meters in the sense that the public understand a meter; these instruments are more akin to steam gauges, etc. They may be arranged to record the movements of their indicators if desired, but even then they only measure certain conditions of the current, the pressure and the rate of flow respectively. The principle of these measuring instruments is very simple. The electric current is passed through a coil of wire, thus setting up a magnetic field in its immediate neighbourhood. A magnetic needle, fixed upon a spindle, is placed within the sphere of influence of the coil, and is deflected according to the strength of the magnetic field produced by the current in the coil. But how can we distinguish between volts and amperes, between pressure and rate of flow?

What is the difference between a voltmeter and an ammeter? The only difference in construction is that in the voltmeter the current has to pass through a coil of very fine wire, while in the ammeter the coil is made of a heavy or coarser wire. It is difficult to find any very suitable analogy for this point, but suppose we desire

to measure the rate of flow and the pressure of the wind. To measure the former, we erect a very light windmill on the top of a pole, and we adjust the mechanism so that when a certain amount of wind has passed, the windmill will have been driven round a definite number of revolutions. We might arrange that half a mile of wind would turn the windmill fifty thousand times, so that we would use means of registering the number of revolutions, and by this we could reckon the rate of flow of the wind. To measure the pressure of the wind we shall be content with a rather rough-and-ready apparatus for the sake of our analogy. We erect a pressure plate held forward by a strong spring of known tension. We can then note the pressure of the wind against the power of the spring. Such an arrangement would not be very accurate, and even properly arranged pressure plates are seldom used in observatories, as we have mathematical tables by which the pressure may be calculated from the rate of flow. However, the point of assistance to us, by way of analogy, is that when we measure the rate of flow of the wind we place as little obstruction as possible in its path, the small windmill being made of aluminium and delicately poised. In the ammeter by which we measure the rate of flow of an electric current we place as little resistance as possible in the path of the current, hence the large conducting wire in the coil, which offers practically no resistance. To measure the pressure of the wind, we place a very considerable resistance in its path, and then note the effect produced. To measure the pressure (volts) of an electric current we place a considerable resistance in its path, making it go through a coil of very fine wire.

Leaving the wind analogy out of account, we may now get a clearer view of the matter in this way. In

the ammeter we require practically no pressure to send the current through the heavy wire, hence the variations in the magnetic field will be due to the rate of flow of the current, which is the same at all parts of the circuit. In the voltmeter we have, on the other hand so blocked the way of the current that it is a reading of its pressure we get. More accurate voltmeters and ammeters are made, just in the same manner as the siphon recorder is a more delicate form of the needle telegraph or needle galvanometer. It will be remembered that in the siphon recorder there is a stationary magnet and a moving coil. These "moving coil" voltmeters and ammeters do not have the whole of the current to be measured passed through them, but only deal with a definite proportion of the whole current. There are also electro-static voltmeters and ammeters, but the instruments just described will serve to show how we measure the pressure and the rate of flow of an electric current.

For our present purpose, the consumer's meter does not concern us, but in closing the subject of measuring it may be noted that in this case it is the energy possessed by the electric current which is measured and paid for. This may be registered by a small electro-motor in the meter, or by the chemical effect of the electric current, and by other methods. In this case the unit was laid down by the Board of Trade, and is called the Board of Trade unit (B. T. U.). This is defined as 1000 watts per hour, a *watt* being a current of one ampere at the pressure of one volt.

CHAPTER XII

WAVES IN THE ETHER

Newton's theories of light disproved—Electric waves and light waves—Experimental proof of relationship between light and electricity—A simple analogy—The connection between the wave-length and the frequency—Ether waves have totally different properties—Ether waves convey energy—Experimental proof that light, radiant heat, and electric waves are all of the same nature.

LONG before man had discovered experimentally the existence of electro-magnetic waves in the ether—as now used in wireless telegraphy—he had abandoned definitely the idea that light was any form of matter, as had been the scientific creed in Sir Isaac Newton's time.

Professor Thomas Young, of London, and other physicists, disproved Newton's theories and established firmly the idea of an all-pervading medium in which wave disturbances could be produced. To-day we have no doubt that light is merely a series of very short waves in the ether. It is unnecessary to prove the existence of the ether in these days of wireless telegraphy, for surely every thoughtful man must be persuaded of its real existence.

As electric waves and light waves are both disturbances in the same great ether ocean, there is bound to be some relationship between the two phenomena. This relationship was proved by experiment in 1845, when Michael Faraday, working at the Royal Institution (London),

rotated a beam of polarised light by means of a powerful magnet.

As all ether waves are of the same kind, and as they all travel with the same velocity, it is obvious that they can differ only in wave-length. In other words, the only difference between light waves and radiant heat waves lies in the distance between the crests of the successive waves. Suppose we had a float or plunger of some kind with a handle attached to it, so that we could conveniently move it up and down at the centre of an imaginary pond of still water. If we were to move the plunger up and down very slowly the waves would follow each other at some considerable distance apart, whereas if the movements of the plunger were rapid the waves or ripples would follow close upon one another's heels. Far more waves would arrive at the shore in one minute when the plunger was moved rapidly. In order to compare the different sets or trains of waves we could measure the distance from the top or crest of one wave to the crest of the following wave. Of course, it would make no difference if we measured the distance from the depression or trough of one wave to the trough of the next wave, or if indeed we measured the distance between any two corresponding points on neighbouring waves. This is what we call the *wave-length.* It will be observed that it has nothing whatever to do with the length along the front or ridge of the wave. By *wave-length* we simply mean the distance between two successive waves. Possibly some readers would be more inclined to call this the width or breadth of the wave.

When we vibrate the plunger rapidly we produce waves of short length. We see that there is a distinct connection between the rate or *frequency* of

vibration and the length of the waves produced. The quicker we vibrate the plunger, the shorter will be the resulting waves. As the velocity of travel of all ether waves is the same, the connection between the frequency and the resulting wave-length is very simple. In one second of time every ether wave will have travelled a distance of 186,000 miles. Therefore if 1000 waves are set up by the vibrator during one second, the first will have travelled to a distance of 186,000 miles when the last wave is ready to start. In other words, there will be 1000 waves equally spread over a distance of 186,000 miles. We do not require pencil and paper to calculate the wave-length in this case, for if 1000 waves occupy a space of 186,000 miles, it is obvious that each wave will occupy a space of 186 miles. We should say, therefore, that the wave-length in this case was 186 miles.

Some of the ether waves used in wireless telegraphy are measured in miles, while, on the other hand, ether waves as short as one two-hundred-and-fifty-thousandth part of an inch have been measured. It is of course quite impossible to realise the smallness of such dimensions, but we can appreciate the tremendous range of different wave-lengths existing in the ether.

We have seen that the whole difference between any one ether wave and another is in its length or the spacing between the waves, and, of course, there must be a corresponding difference in the frequency or number of vibrations per second. It is marvellous that these ether waves which only differ in this way possess such very different properties.

Commencing with the longest ether waves, we find that these affect the detectors used in wireless telegraphy. We have seen that these waves may be spaced miles apart, but other electric waves of the same class

have been produced as close together as six waves within one inch. Even this is very long when compared with the majority of ether waves. When ether waves only measure a few thousandths of an inch they produce heating effects, and we speak of them as waves of *radiant heat.* As long as waves are longer than one thirty-thousandth part of an inch we call them dark-heat waves, for they do not affect our vision, but as soon as they step over that boundary line they do affect our eyes. They cause the sensation of red light when there are about thirty-four thousand waves to the inch. If the waves are still somewhat shorter—or closer together—they produce the sensation of orange colour; still decreasing in wave-length they produce the sensation of yellow, then green, then blue, and when they have become so short that sixty thousand occupy one inch they produce the colour sensation of violet. After that they cease to affect our eyes altogether, and we call them waves of *ultra-violet light,* signifying that they are beyond the violet end of the spectrum.

Although these same waves of ultra-violet light fail to stimulate our sensory organs of vision, they very actively affect the chemicals upon a photographic plate. Because of their chemical properties these waves are often called *actinic* waves.

It is apparent that all these ether waves are conveying energy to great distances. A transmitter in wireless telegraphy acts upon the ether ocean. This wave energy may be carried through the ether broadcast across the Atlantic Ocean, and, strange to say, an insignificant little detector on the far distant shore receives sufficient energy to cause some change within it, and in this way signals are produced.

All these ether waves may be *reflected* and *refracted,*

or bent out of their straight course. We are quite conversant with the substances which will reflect *light* waves and *heat* waves, while *electric* waves may be reflected by a sheet of metal. We are also well aware of the transparent substances which will bend light waves, the most common in practice being glass prisms and lenses. In a similar manner we may bend heat waves by passing them through a prism of rock-salt, while electric waves are similarly refracted in passing through a prism of paraffin wax.

CHAPTER XIII

WHAT IS ELECTRICITY?

In answer to the title—The nature of an electric current—The original meaning of positive and negative electricities Our present conceptions—The electron—Continuous and alternating currents—The nature of an electric discharge—An analogy of the electron current—The cause of the magnetic field—The connecting link between matter and the ether.

ALTHOUGH it is not necessary that we should form any idea of the nature of electrical phenomena in order to understand the working of telegraphs and telephones, it may be of advantage to consider very briefly the present conceptions concerning these.

We cannot answer the question which stands as the title to this chapter, but we believe we can give an adequate reply to the question, What is an electric current?

Our present creed is based upon the *electron theory*, which is quite romantic in its wide scope, but I need do no more than merely touch upon one or two points which are applicable to our present subject, as I have written very fully upon the electron theory recently.*

First of all we must see the meaning of the terms *positive* and *negative* electricity, which I have avoided purposely in the foregoing text.

That there are two kinds of electrification was evident from the earliest experiments. We know that an electrified body attracts any light object. In order to examine

* *Scientific Ideas of To-day* (popularly explained). Seeley & Co., Ltd. 5*s.* nett.

the conditions of this attraction we suspend, by means of a thread of silk, a very light ball about the size of a pea and made from the pith of an elm tree. We use this pith ball simply because of its small weight; it will be so easily moved. We suspend the silk thread from a glass pillar or other insulator, so that whatever electrical charge we give to the pith ball cannot escape from it. After "exciting" a vulcanite rod, by means of a fur rubber, we bring the rod towards the pith ball, which immediately jumps forward to meet the rod. We withdraw the rod, to which the ball clings, but in freeing the ball from the rod we are careful not to touch the ball, as we wish it to retain the charge of electricity the rod has given to it. We again bring the electrified vulcanite rod towards the pith ball, which is now electrified also, whereupon we find that it is forcibly repelled from the rod. Do electrified bodies repel one another then? Not necessarily so, for if we excite a glass rod by means of a silk rubber and bring this electrified rod towards the electrified pith ball, we find that the ball is attracted to it, although the ball still flees from the electrified vulcanite rod. To make this matter as clear as possible, it will be an advantage to suspend two pith balls from separate supports. We first of all electrify one ball by contact with the electrified vulcanite rod, and we find that this electrified pith ball attracts the other non-electrified one. We discharge the electrified ball by simply touching it with the hand, and thus allowing its charge to escape to earth. There is, of course, no sensation produced by so small a charge. We then electrify the same pith ball by contact with the electrified glass rod, and we find that this ball attracts the other non-electrified ball just as it did before. Therefore any electrified body will attract a non-electrified body.

What is Electricity?

When we electrify one ball by the vulcanite rod and the other ball by the glass rod, we still find the same attraction between the balls. It is only when we electrify both balls by the vulcanite rod, or both by the glass rod, that we find repulsion. Electricity produced by a glass rod used to be called *vitreous* electricity, and that obtained from sealing-wax, or vulcanite, was known as *resinous* electricity.

Franklin suggested that the two different states of electrification were due to a surplus in one case and a defect in the other, of a mysterious fluid, but as to which was which he could do no more than guess. He elected to credit glass with the excess of the fluid, and so he said that it was positively electrified, or charged with positive electricity. On the other hand, he supposed that a body electrified by sealing-wax had a deficiency of the electric fluid, and so he said that it was negatively electrified, or, in other words, he said that the sealing-wax produced negative electricity.

Our present creed is that the atoms of all matter are composed of different congregations of particles or units of negative electricity revolving within a sphere of positive electricity. These ultimate particles of negative electricity have been christened *electrons*, while some have preferred to call them *corpuscles*, but we must keep in mind the fact that they are not matter; they are the stuff that matter is made of. But can these electrons be detected in nature, or are they purely hypothetical? Of course we cannot hope to handle them or see them, but we may prove their existence by the effects which they produce; indeed, we know really more about these electrons than we do about atoms of matter. Physicists have determined the mass, the electric charge, and the velocity of these invisible electrons.

We believe that there are detachable electrons which can pass from one atom to another. A steady motion of such electrons from atom to atom along a wire constitutes a *continuous* or *direct* electric current; while a surging to and fro of these electrons is described as an *alternating* current.

A sudden expulsion of those detachable electrons from one body to another constitutes an electric discharge, and we picture the electrons, in this case, being shot off like bullets from the one object to the other. When we rub a stick of glass with a piece of silk cloth we give the glass rod an opportunity of handing over some spare electrons to the silk. We still say that the glass rod is positively electrified, although it is suffering from a deficiency of electrons, for we picture its atoms having given up negative particles, thus leaving the positive spheres to predominate. It must be remembered that this sphere of positive electricity is purely hypothetical, as we cannot separate it from the atom of matter, while, on the other hand, we have direct experimental proof of the negative electrons.

Throughout the preceding pages we have pictured currents of electricity flowing along wires and supplying the necessary energy for telegraphs and telephones, but now we can form some conception of what is really taking place. In the first place we picture myriads of atoms hard at work handing on spare electrons from atom to atom, and in order to impress this phenomenon upon our minds the following analogy may be of service. There is a game which I have seen children play, and which may serve as an analogy of this process. The children stand in a long row, and at one end of the row is placed a heap of objects—say a large number of pennies. At a given signal the children pass the coins along from one

to the other, till they reach the other end of the row where they are deposited in a heap. No child is allowed to accept a coin till he or she has passed on the previous one. Another row of the same number of children stands parallel to the first row, and these are also provided with an exactly similar number of pennies. The game being, of course, a battle royal between the two parallel rows as to which row can transmit the whole of the coins in this fashion from the one end of their line to the other in the shortest space of time. Only one row of children concerns us in our analogy, and we picture the little ones as representing the atoms in a length of metal wire. Each atom passes on a corpuscle to its neighbour and accepts another corpuscle from the neighbour on its other side. For the sake of analogy we start the game with each child having one coin in his or her hand, so that the moment the signal is given, representing the closing of the electric circuit, a complete transfer commences simultaneously all along the line. Instead of having a heap of coins at one end, we might arrange the children in a circle and give them one coin each, so that the coins would pass round and round the circle. This is what we understand by a complete electric circuit; a battery or a dynamo acting as a pump in the circuit. We may break the complete circuit, and then there can be no passing on of corpuscles. The atoms try to pass their corpuscles along, but the break acts as a barrier. On testing the electrical conditions of the ends of the severed wire we do find a small difference of potential.

The first arrangement of the children's game, in which we had the children standing in a row, is somewhat analogous to an earth circuit in electrical affairs. The first child kept picking up coins, passing them along, and the last child deposited the coins in a heap as they

were received. We therefore imagine the first atom at the one end of a wire, which is dipping into the earth, to be helping itself to corpuscles one at a time, passing them along, and the last atom at the other end of the wire depositing these corpuscles in the earth. There is, of course, a battery or a dynamo again acting as a pump.

This motion of the electrons is only part of the phenomenon, for as these move they disturb the surrounding ether, and produce what we know as a *magnetic field* around the conductor, and, as already pointed out, it is this intimate connection between electricity and magnetism that gives us the practical telegraphs and telephones of our day. Here we see that the connecting link between matter and the ether is the motion of electrons. It is the enormously rapid revolutions of electrons which cause light waves.

There is a great deal of interest in this electron theory, which has been described by a great statesman as "a bold attempt to unify physical nature, a theory which excites feelings of the most acute intellectual gratification."

While the opening sentence of this chapter is true, there is no doubt that when we once become well acquainted with the electron theory we have gained a distinct advantage; we can see more reason in the different phenomena connected with telegraphs and telephones.

APPENDIX I

A SHORT HISTORICAL NOTE

—— B.C. Man discovers lodestone and observes its magnetic properties. These were known at least one thousand years before the dawn of the Christian era.

— – B.C. Man observed the attractive property of rubbed amber. The earliest record of this phenomena is 600 B.C.

A.D. 1600. Dr. William Gilbert, one of Queen Elizabeth's physicians, discovered that amber was not the only substance which showed the property of attraction when rubbed.

1790. Professor Galvani, of Italy, made his historical discovery with the legs of a frog.

1800. Professor Volta, of Italy, following up this experiment, discovered the chemical means of producing an electric current.

1819. Hans Christian Oersted, of Denmark, discovered that an electric current in a wire affected a neighbouring magnet.

1820. Arago (France) and Sir Humphry Davy (London) discovered independently that a piece of iron became magnetised by passing an electric current through an insulated wire surrounding it.

1825. The first soft-iron electro-magnet invented by Sturgeon (London).

1837. Morse (U.S.A.) patented his now universal system of telegraphy, employing soft iron electro-magnets.

1822. A practical galvanometer was invented by Schweigger.

1837. Needle telegraph (galvanometer) patented by Cooke and Wheatstone, in London.

1838. Steinheil (Munich) discovered that an earth circuit might be used in place of a return wire.

1837. Page (U.S.A.) discovered that if an iron rod was quickly magnetised and demagnetised it emitted a sound.

1860. Reis (Germany) transmitted music and words, the latter only imperfectly.

1876. Graham Bell (U.S.A.) invented a magneto-telephone and transmitted speech.

1879. Hughes (London) invented a carbon microphone transmitter.

1896. Practical wireless telegraphy was set on foot by Marconi (Italy). The practical experiments were carried out in Great Britain, but were based upon discoveries made by Continental scientists.

APPENDIX II

TAPPING A TELEGRAPH CIRCUIT

A FEW words may help to clear up a possible difficulty in connection with the use of condensers when tapping a telegraph wire in order to use a field telephone.

The one terminal from a portable field telephone is connected to an existing telegraph wire and the other terminal is earthed, the same arrangement being made at the distant point with which communication is to be established. This looks as if we had earthed the telegraph wire, and rendered it useless for telegraphic purposes. This would happen but for the fact that a condenser has been inserted in the telephone circuit. This condenser prevents the telegraph current getting through the telephone circuit, for the current cannot pass through the insulation between the condenser plates, but the alternating current of the telephone may operate across the condenser. I fear that any attempted analogy for this would be clumsy, but the matter becomes quite simple when we consider it from the point of view of the electron theory.

The telegraph current is a *direct* or *continuous* current, and we have seen in chapter XIII that this phenomenon is due to a steady locomotion of electrons; a continuous chain of atoms handing electrons along from atom to atom. As the condenser forms a break in the telephone

circuit, it is clear that there can be no continuous chain of atoms, so that it is impossible for the *direct* current to pass that way. Hence it is that telegraph messages may be sent along the telegraph wire without in any way disturbing the field telephone which has tapped the telegraph line.

On the other hand, the telephone current is not a *direct* but an *alternating* current, and we have seen that in this case the electrons are not handed along the line, but merely surge to and fro. These rapidly moving electrons can affect one another across the condenser insulation, and we have no difficulty in setting up a surging to and fro of electrons in the circuit. Hence the telephone current is free to operate, although a telegraph current is cut off.

When a signalling instrument called a *buzzer* is used on the telephone circuit, a second condenser is introduced, but this is merely to prevent excessive sparking in connection with the buzzer.

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